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Effects of Construction of the Digital Multipurpose Range Complex (Dmprc) on Riparian and Stream Ecosystems at Fort Benning, Georgia

SERDP Project RC-1186

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14. ABSTRACT
The goal of this project was to assess the effects of construction of the construction of the Digital Multipurpose Range Complex (DMPRC) on riparian and stream ecosystems at Fort Benning. Assessment of DMPRC impacts involved application of a number of the measurements and approaches used to identify military training impacts on riparian and stream ecosystems, with particular emphasis on measurements that proved to be good indicators of disturbance impacts in the ongoing study. These included measures of impacts on riparian vegetation and soil processes, stream hydrology and water quality, and stream biota and their habitat. Because Bonham Creek and Sally Branch were moderately disturbed prior to DMPRC construction, construction effects on these streams were likely not as great as would be observed in more undisturbed streams. Implementation of the DMPRC may offer an opportunity to improve biological conditions in Bonham Creek and Sally Branch if sediment delivery to these streams is reduced by more effective erosion controls.

15. SUBJECT TERMS
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EXECUTIVE SUMMARY

The goal of this project was to assess the effects of construction of the construction of the Digital Multipurpose Range Complex (DMPRC) on riparian and stream ecosystems at Fort Benning. This work was supported by add-on funding first received in September 2004 to our original project (SI-1186). The final report for the original project was submitted in June 2007. Field studies to determine effects of construction of the DMPRC were completed in December 2008 and this addendum to the final project report summarizes the results of those studies.

Assessment of DMPRC impacts involved application of a number of the measurements and approaches used to identify military training impacts on riparian and stream ecosystems, with particular emphasis on measurements that proved to be good indicators of disturbance impacts in the ongoing study. These included measures of impacts on riparian vegetation and soil processes, stream hydrology and water quality, and stream biota and their habitat. Our study stressed impacts to water quality because of the potential for significant impacts and the regulatory scrutiny of water quality issues at Fort Benning. The Bonham Creek and Sally Branch watersheds were chosen for study because DMPRC construction was likely to have the greatest impacts on riparian and stream ecosystems of these catchments.

There were few indications of soil movement from the upland slopes of the DMPRC, a reflection of the effectiveness of the grass establishment there in regard to soil stabilization. Similarly, litterfall, net primary productivity, and microbial biomass data from forest plots bordering the DMPRC indicated no significant effect of proximity to the DMPRC disturbance. However, soil nitrogen mineralization was stimulated in the same plots. Consequently, apart from stimulation of nitrogen mineralization, there were few biogeochemical or vegetation responses to DMPRC construction. In contrast, sediment pin data from crossings on both Bonham Creek and Sally Branch indicated significant erosion near those crossings during 2007, a drought year. The 2-3 month lag time between crossing construction and implementation of soil stabilization measures likely contributed to soil movement on those sites. However, once soils were stabilized, export declined even under higher rainfall conditions such as those of 2008.

Results of our water quality studies indicate that water quality in Bonham Creek and one of its tributaries (D13) was significantly impaired by large sediment inputs and, to a lesser extent, by increased inorganic nitrogen concentrations beginning in late 2005 and early 2006. There was evidence that the sediment inputs to Bonham Creek were declining somewhat in 2007 as most construction activities in the watershed were completed. However, beginning in 2007 there was evidence that sediment inputs to Sally Branch increased markedly as shown by high storm suspended sediment concentrations. In addition, storm inorganic nitrogen concentrations increased sharply in Sally Branch in 2007. Sediment pin data from stream crossings reflected soil loss along the banks of both streams in 2007.

Results of our analyses on impacts of DMPRC construction on stream biota indicate virtually no impact in Sally Branch, minimal and short-term (1-2 y) impacts in Bonham Creek, and significant impacts in D13, the tributary of Bonham Creek. D13 in particular showed alterations in a suite of biotic and abiotic conditions including temporal shifts in streambed stability, increases in algal biomass, and alterations in benthic macroinvertebrate and fish assemblage richness, abundance, and/or composition. It seems likely that increased inorganic nitrogen and suspended sediment concentrations were at least partially responsible for biotic impacts. Most biotic and habitat impacts manifested for 1 to 3 y, which in almost all cases were undetectable in 2008 as stream communities recovered.

We believe the contrasting, stream-specific results from our biotic water quality work (i.e., large biotic impacts in one system, virtually no impacts in another) are due to large differences in stream conditions in the three catchments prior to DMPRC construction. The Bonham Creek mainstem and Sally Branch were moderately disturbed prior to construction due to high disturbance levels in some of their tributary streams as have been shown in our earlier work; in contrast, biotic integrity in D-13 prior to DMPRC construction was relatively high. Thus, additional effects of DMPRC construction in Bonham Creek and Sally Branch may have been difficult to detect for biotic communities that already were somewhat depressed from prior disturbance in these catchments. In contrast, effects of construction on the D13 tributary of Bonham Creek were more readily observed because it was less disturbed prior to construction.

Because Bonham Creek and Sally Branch were moderately disturbed prior to DMPRC construction, construction effects on these streams were likely not as great as would be observed in more undisturbed streams. This is particularly true for biological impacts, and is corroborated by the more severe impacts observed in the Bonham Creek tributary D13. Implementation of the DMPRC may offer an opportunity to improve biological conditions in Bonham Creek and Sally Branch if sediment delivery to these streams is reduced by more effective erosion controls. Therefore, we recommend continued monitoring of biota and key water quality parameters (particularly suspended sediments and inorganic nitrogen) in these streams to identify possible recovery from past disturbances including historical agricultural as well as previous military training impacts.

The project team briefed Fort Benning personnel on our findings in June 2006, in November 2007, and in July 2008.

Background and Project Objectives

Assessment of impacts resulting from construction of the Digital Multi-Purpose Range Complex (DMPRC) on riparian and stream ecosystems at Fort Benning, Georgia, was initiated in September 2004. This effort was funded as an addendum to our originally funded project studying the impacts of military training and land management on riparian and stream ecosystems and the effects of restoration approaches involving stabilization and revegetation of ephemeral drainages and woody debris addition to stream channels (SERDP Project Number SI-1186). Assessment of DMPRC impacts involved application of a number of the measurements and approaches used to identify military training impacts on riparian and stream ecosystems, with particular emphasis on measurements that proved to be good indicators of disturbance impacts in the ongoing study. These included measures of impacts on riparian vegetation and soil processes, stream hydrology and water quality, and stream biota and their habitat. Our study stressed impacts to water quality because of the potential for significant impacts and the regulatory scrutiny of water quality issues at Fort Benning.

The objectives of the DMPRC assessment project were:

(1) To determine effects of DMPRC construction on riparian ecosystems, including soils and vegetation;
(2) To determine effects of DMPRC construction on stream ecosystems, including hydrology, water quality, and biota and biotic habitat.

Project Overview

The Bonham Creek and Sally Branch watersheds were chosen for study because DMPRC construction was likely to have the greatest impacts on riparian and stream ecosystems of these catchments. For the riparian assessment, several reference and potentially impacted plots were chosen for study. The reference plots were located in riparian areas of nearby catchments outside the DMPRC area, whereas the potentially impacted plots were located in riparian areas of Bonham and Sally catchments that were left intact but were just downgradient from areas that were cleared for DMPRC construction (Fig. 1). For the stream studies an upstream-downstream approach was used with stations chosen in Bonham Creek and Sally Branch that were upstream and downstream of the DMPRC area (Fig. 1). In addition, we assessed impacts on stream water quality and biota of a small 2^{nd}-order tributary of Bonham Creek (referred to as D13) that was also within the DMPRC area. D13 was chosen for study because we had several years of data collected as part of our ongoing SERDP project prior to DMPRC construction activity and we would be able to more clearly observe potential DMPRC construction impacts. Impacts to D13 were assessed using a control-treatment approach, with a stream draining an adjacent catchment (referred to as D12) but not within the DMPRC area and for which we also had several years of previous data serving as the control. We also used an upstream-downstream approach in the D13 impact assessment

but, as with the Bonham and Sally assessments, we had limited data prior to the initiation of DMPRC forest clearing.

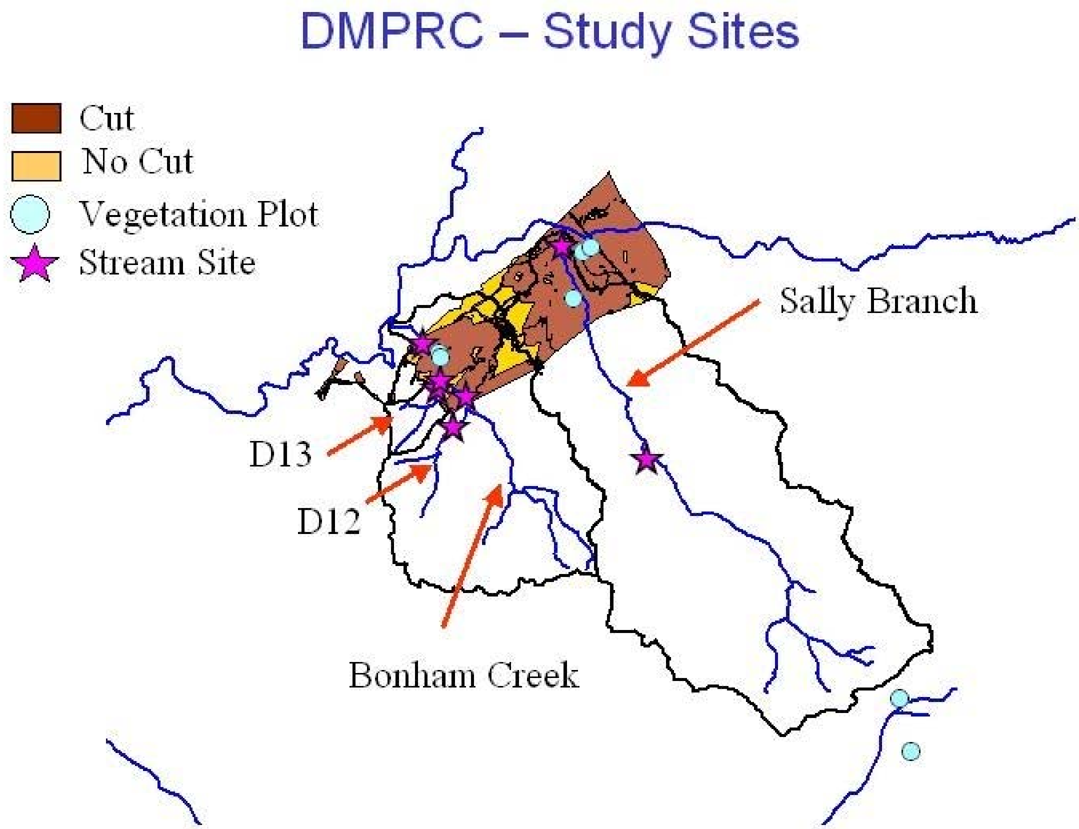


Figure 1. Location of riparian plots and stream sampling stations for the DMPRC impacts study.

In our previous work at Fort Benning, we developed a quantitative, catchment-scale metric for disturbance that proved to be an excellent predictor of impacts to stream hydrology, water quality, and biota. This metric was essentially the proportion of the catchment in a highly disturbed state (denuded of vegetation with soils highly disturbed). It was defined as the % of catchment area identified from aerial photos and digital elevation models as bare ground on slopes ≥ 5% and unpaved roads (Maloney et al. 2005). We calculated this metric for the Sally and Bonham Creek catchments before and after vegetation clearing for the DMPRC. The increases in disturbance level due to DMPRC construction are given in Table 1 below.

Table 1. Catchment-scale disturbance levels for our 3 study streams prior to and after clearing for DMPRC construction.

Study Catchment	**Disturbance Level – Prior to DMPRC**	**Disturbance Level – After DMPRC**
Bonham Creek	11.5%	23.4%
Sally Branch	5.4%	12.0%
D13	3.6%	11.2%

Our previous studies included streams with disturbance levels ranging from 2 to 15% (Maloney et al. 2005). In general, we found that negative impacts on a variety of water quality and biological parameters increased with increasing disturbance level with an apparent threshold value of between 6 and 8% where impacts became significant (Maloney et al. 2005, Houser et al. 2005, 2006, Maloney and Feminella 2006, Maloney et al. in press). Disturbance levels for two of the study watersheds (Sally Branch and D13) were less than this threshold value prior to DMPRC construction, but increased to values well above this threshold in each of the study watersheds with DMPRC construction (Table 1). This change would suggest that significant impacts might be observed in these streams. However, our previous studies focused only on 1^{st}- and 2^{nd}-order streams at Fort Benning, and Bonham Creek and Sally Branch are considerably larger streams (3^{rd} order); thus, they may not exhibit similar disturbance level/impact relationships as that of D13 and other smaller catchments.

Following is a summary of our most salient results on DMPRC impacts on riparian and stream ecosystems through the end of our study in autumn 2008.

Impacts of DMPRC Construction

RIPARIAN VEGETATION AND SOILS

Methods

DMPRC plots: Four plots were established at the riparian outlets of ephemeral streams emanating from the DMPRC construction zone. These were established in late September, 2004 (prior to initiation of construction) and monitored prior to, during, and after construction. Data from these plots were compared to two reference areas that had been monitored for several years in a SERDP study. Two of the four DMPRC research plots in D14 were clearcut and bulldozed in August 2007 but were re-installed in close proximity to the original locations.

DMPRC and control plots were equipped with litter traps and sediment pins (described in section on stream crossings). Soil nitrogen mineralization and microbial biomass were also measured on these plots.

Sediment pins: To estimate current sedimentation rates, we used a sediment pin approach. Sediment pins were installed along the creek bank at four stream crossings along Bonham Creek in October, 2006. In January 2007, sediment pins were installed at three stream crossings along Sally Branch. Locations on Bonham were near newly constructed stream crossings upstream of the Hourglass Road crossing of Bonham Creek. Along Sally Branch, the first stream crossing sampled was located at the creek intersection with Resaca Road. The two other sampled crossings were upstream from that point. For each stream crossing, sediment pins were installed on both sides of the road and along the stream to provide a representative sample of sediment deposition or scouring that was occurring along the banks. A generic diagram of the sampling distribution at stream crossings is provided in Fig. 2. At each stream crossing, quadrants separated by the road and stream were established to calculate and analyze mean sediment accretion or scour. A total of 308 pins were established over the 7 monitored stream crossings. However, during 2007, most of the erosion pins near Sally Branch were eradicated by construction efforts there (Fig. 3) but were relocated elsewhere.

Sediment pins consisted of 122 cm rebar with large metal washers soldered onto the center. The sediment pins were pushed into the ground until the washer was flat with the soil surface (at 61cm). The washer served as the reference for each pin and the depth to the washer or depth to the soil below the washer was measured twice a month. However, after the second week in June, 2007, no more measurements could be recorded for two of the three Sally Branch crossings because erosion control rip rap had been deposited atop the sediment pins (Fig. 3). Sediment loss or accumulation was calculated for individual pins by comparisons of departures from the previous sampling. These calculations were then averaged to determine the mean sediment accretion/scouring for the entire stream crossing.

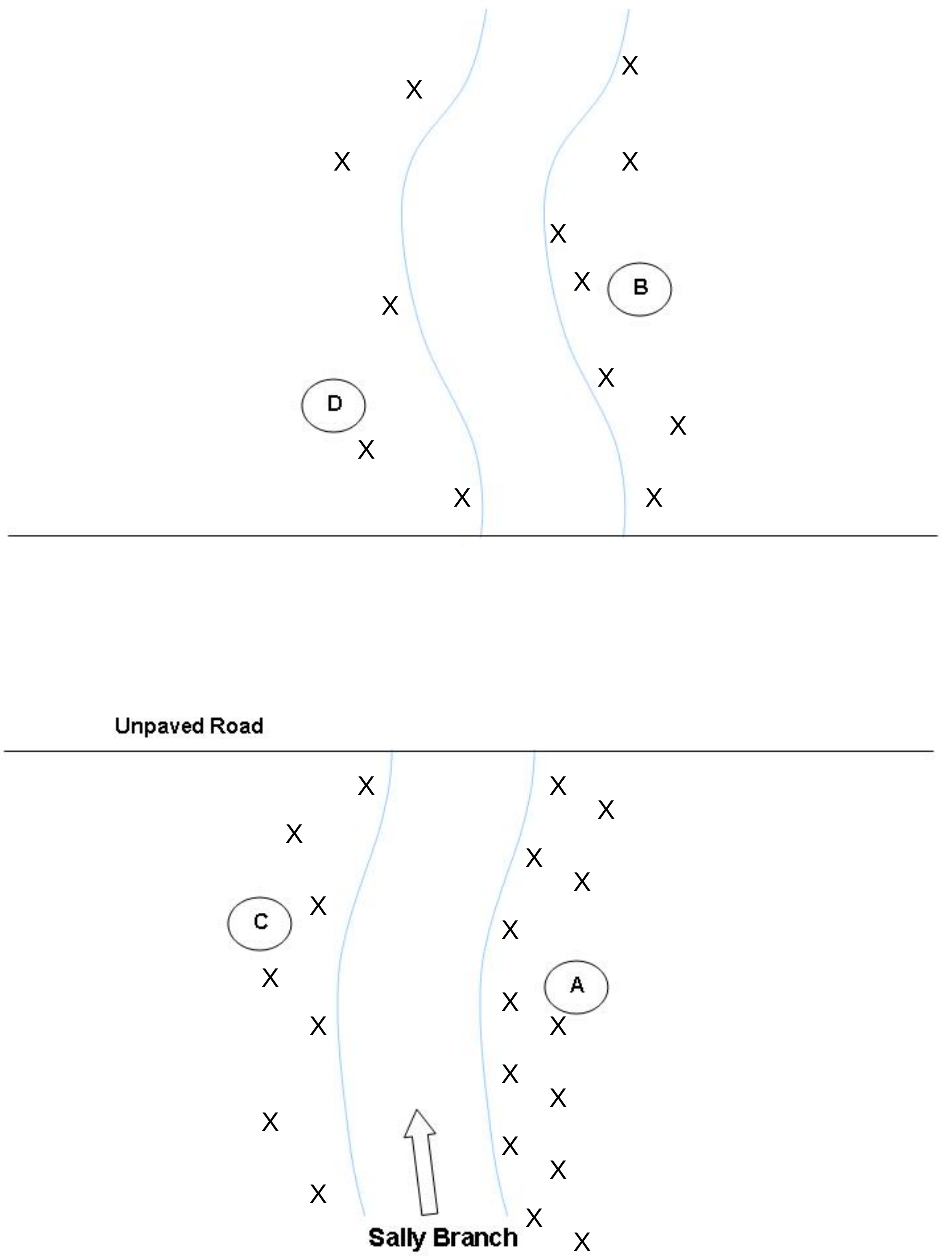


Figure 2. Example of sediment pin locations used to assess sedimentation and scouring along stream crossings in Ft. Benning DMPRC. The circled letters denote quadrants and the Xs denote sediment pin locations.

Figure 3. Photos of rocks that were placed atop sediment pins near Sally Branch crossings.

Results

Precipitation: Precipitation has a direct influence on the rates and patterns of sediment movement. The study period occurred during the most pronounced drought since 1953. The very low precipitation has undoubtedly reduced the magnitude and number of runoff events and has influenced the results to an unknown extent.

To assist with the interpretation of sediment data, daily precipitation information from Columbus, GA are provided (Fig. 4). During the monitoring period in 2007, precipitation was characterized by regular moderate rain events during January and February. However starting in early March there was a significant dry period where only one rain event greater than 2 cm occurred (mid-April). This dry period continued until early June when regular rain events >2 cm per day occurred until late July (Fig. 4). After mid-August, the few rain events that occurred were generally less than 1 cm. Evaluating sedimentation trends relative to precipitation, some stream crossings had quadrants with gradual scouring trends over the course of the monitoring period (e.g., Bonham 1 and Sally 1). Not surprisingly, given the extent of the current drought, there is little evidence of mean sedimentation trends related to individual rain events or periods. However, in 2008, rainfall amounts and patterns were much more similar to the 30-yr norm.

Temperature: During summer 2005 through summer 2006 and from winter 2007 through winter 2008, higher than normal temperatures (1971-2000) were observed (Fig. 5). This combined with the lower precipitation in 2006 and 2007 may have influenced microbial biomass carbon and nitrogen values on the plots.

DMPRC plots: Sedimentation data from the four DMPRC plots indicated that there was very little accumulation or export (Table 2) apart from some deposition in mid 2007 on the two DMPRC plots that were destined for eradication from construction. We believe that the lack of accumulation is primarily due to the retention of a vegetated zone between the upslope, disturbed DMPRC and the riparian outlets of the ephemeral streams. The control plots are very stable regarding sediment movement as would be expected.

Few significant changes have been noted in forest productivity, species composition, or microbial biomass in comparisons between DMPRC vs. control plots. Nitrogen mineralization rates were significantly higher during autumn, 2006, spring, 2007, and spring, 2008 on DMPRC plots (Table 3). In addition, DMPRC levels of nitrogen mineralization were numerically higher than control plot values for all seasons from 2005 through 2008. These trends suggest that microbial communities responsible for nitrogen mineralization were stimulated by close proximity to the DMPRC. However, microbial biomass carbon was significantly higher on control plots during winter, summer, and autumn of 2005 but did not differ statistically during any other season or year. Also, no numeric trends were apparent (Table 4). Similarly, microbial biomass nitrogen differed significantly (control plot levels being higher) between sets of plots for winter and autumn of 2005 but not for any other season from 2005 – 2008 (Table 5).

Annual litterfall mass in 2006 and 2007 differed significantly between groups of plots with the control being higher in 2007 and the DMPRC being higher in 2006 (Table 6). This suggests that these differences may not be associated with a treatment effect but, rather, may reflect natural variation among stands of trees. Similarly, treatment differences in composition of litterfall during 2007 and litterfall nutrient content in 2006 and 2007 suggest that natural variation played a role there also (Tables 7, 8). No differences were found for N:P and C:N ratios in litterfall for any season or year (Tables 9, 10).

Sediment Pins: The average temporal patterns for sediment loss / accretion on crossings at Bonham Creek and Sally Branch are provided in Figs. 6a & b respectively. There was considerable variability both between and within stream crossings. However, most stream crossings showed net export from stream banks with some quadrants showing substantial losses. Along Bonham Creek, Bonham lower was somewhat of an exception with three of the five quadrants showing net accretion (Fig. 6a). All of the remaining quadrants monitored along Bonham Creek exhibited net scouring. In most cases, the mean loss measured was <4 cm although a mean of >12 cm was observed in one location.

Along Sally Creek, results were less consistent and varied considerably within each crossing. In the first half of 2007, data at Sally lower and upper showed mean quadrant accumulation as high as 8.9 cm and scouring as deep as 11.1 cm. There was no apparent pattern related to quadrant locations (upstream or downstream). In Sally middle, significant levels of sedimentation and scouring were also measured during the course of the monitoring period. However, by late May, 2007 (the last monitoring date prior to the covering of the sample locations by rip rap), 3 out of 4 quadrants at that location displayed deposition between 4 and 7 cm. The remaining Sally crossing exhibited a strong pattern of sediment loss through October of 2008.

When means are compared, some interesting trends appear (Figs. 7, 8). At Bonham Creek, 3 of 4 stream crossings exhibited net losses of stream bank soil ranging from 0.4 to 4.0 cm. Temporal patterns indicate gradual scouring throughout the monitoring period. At Sally Branch, although all three crossings showed net scouring during April and then net deposition during the first week of May, the single crossing where data could be gathered through 2008 exhibited net losses throughout the study period (i.e. 5.2 cm in November).

Table 2. Sediment accumulation rates on plots located near margins of the DMPRC.

	2007		2008	
	Sedimentation rate (cm yr $^{-1}$)		Sedimentation rate (cm yr $^{-1}$)	
Plot	mean	stderr	mean	stderr
D14a	2.72*	1.72	-0.06	0.42
D14b	0.26*	0.26	-0.20	0.20
D2	-0.04	0.04	0.22	0.19
D1	0	0	0	0
F4a	-0.07	0.07	-0.12	0.29
F4c	0	0	0	0

* Plots D14a and D14b were clearcut in August 2007. Data for these plots represent sediment accumulation through July 2007. New plots for D14a and D14b were re-established following the clearcut for 2008.

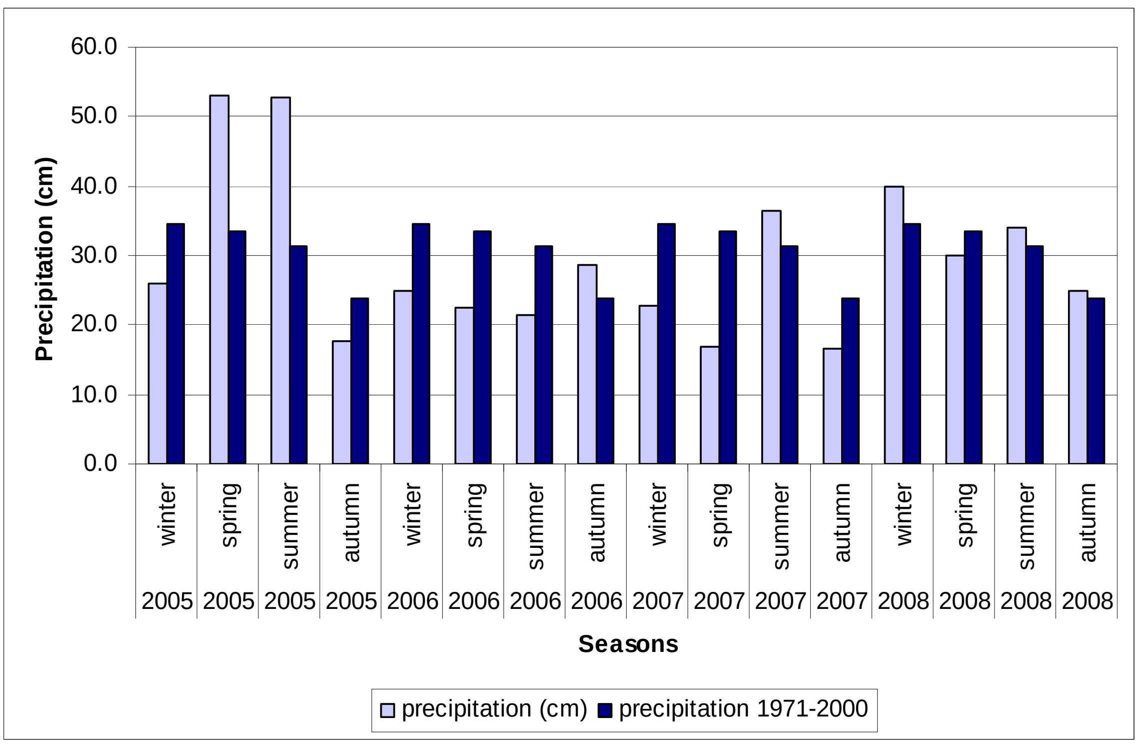


Figure 4. Precipitation at Columbus, GA from Dec. 2004 through Nov. 2008.

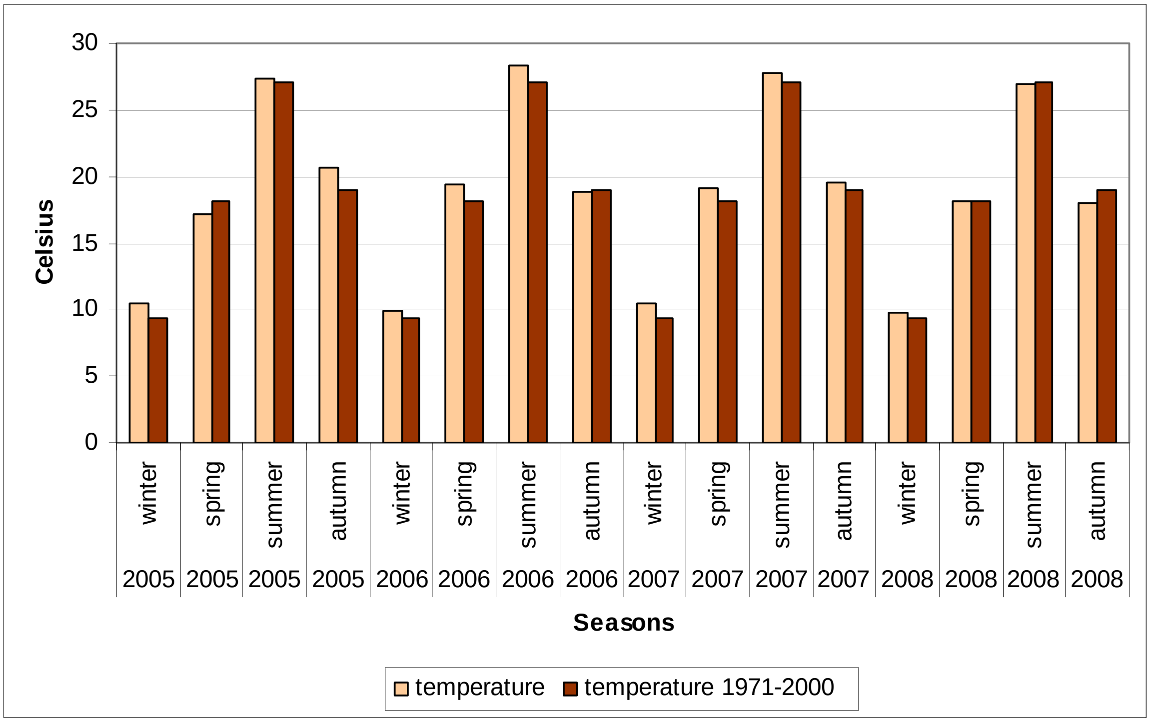


Figure 5. Temperature at Columbus, GA. From Dec. 2004 through Nov. 2008.

Table 3. Total nitrogen mineralized (g ha^{-1} d^{-1}) on control and DMPRC plots located at Ft. Benning, GA (, * = significant difference at 0.01, 0.05 levels respectively).**

		Mean		
Year	Season	Control	DMPRC	Pr > | t |
2005	Spring	110.89	169.34	0.650
2005	Summer	326.75	622.64	0.104
2005	Autumn	66.47	84.63	0.413
2006	Spring	47.25	170.73	0.129
2006	Summer	150.09	317.34	0.160
2006	Autumn	38.69	138.56	0.017*
2007	Spring	52.51	278.55	0.003**
2007	Summer	261.26	333.07	0.655
2007	Autumn	154.45	161.54	0.924
2008	Winter	41.79	224.13	0.067
2008	Spring	110.05	293.54	0.024*
2008	Summer	168.55	337.13	0.110
2008	Autumn	98.14	135.06	0.472

Table 4. Microbial carbon biomass (ug g^{-1} dry $soil^{-1}$) on control and DMPRC plots located in Ft. Benning, GA (, * = significant difference at 0.05, 0.10 levels respectively).**

		Mean		
Year	Season	Control	DMPRC	Pr > | t |
2005	Winter	368.85	141.55	0.032**
2005	Spring	173.45	139.08	0.301
2005	Summer	216.45	124.03	0.069*
2005	Autumn	223.48	112.38	0.086*
2006	Winter	164.89	111.49	0.500
2006	Spring	115.35	71.09	0.392
2006	Summer	131.69	208.62	0.530
2007	Spring	177.56	192.37	0.893
2007	Summer	253.93	217.85	0.668
2007	Autumn	512.3	165.79	0.231
2008	Winter	563.86	484.20	0.214
2008	Spring	791.02	657.26	0.269
2008	Summer	619.64	845.05	0.151
2008	Autumn	263.42	311.38	0.622

Table 5. Microbial nitrogen biomass (ug g^{-1} dry $soil^{-1}$) on control and DMPRC plots located in Ft. Benning, GA (, * = significant difference at 0.05, 0.10 levels respectively).**

		Mean		
Year	Season	Control	DMPRC	Pr > | t |
2005	Winter	41.26	15.69	0.042**
2005	Spring	30.22	27.59	0.722
2005	Summer	38.09	22.29	0.155
2005	Autumn	30.04	14.05	0.032**
2006	Winter	21.23	16.85	0.693
2006	Spring	21.99	13.68	0.363
2006	Summer	25.35	34.23	0.733
2007	Spring	12.83	18.98	0.505
2007	Summer	25.64	25.96	0.971
2007	Autumn	65.79	10.94	0.231
2008	Winter	76.90	57.44	0.372
2008	Spring	46.35	60.24	0.297
2008	Summer	30.37	48.39	0.076
2008	Autumn	20.92	37.71	0.300

Table 6. Comparison of litterfall biomass estimates (g m $^{-2}$ yr^{-1}) on control and DMPRC plots located in Ft. Benning, GA (, * = significant difference at 0.05, 0.10 levels respectively).**

Year	Control	Treatment	Pr > | t |
2005	553	544	0.910
2006	488	579	0.014**
2007	668	417	0.026**
2008	737	676	0.631

Notes:
2005: d1 established in May because d3 was bulldozed
2007: d14a and d14b (DMPRC plots) were bulldozed Aug-Oct so missing data on these plots until we could get in and re-establish plots next to old plots at the end of Oct.

Table 7. Composition of leaves, reproduction and twigs found in litterfall biomass estimates (g m $^{-2}$ yr^{-1}) on control and DMPRC plots located in Ft. Benning, GA (, * = significant difference at 0.05, 0.10 levels respectively).**

Year	Type	Control	Treatment	Pr > | t |
2005	Leaves	455	424	0.539
	Reproduction	46	41	0.716
	Twigs	52	79	0.339
2006	Leaves	428	454	0.425
	Reproduction	16	80	0.165
	Twigs	44	45	0.885
2007	Leaves	433	301	0.035
	Reproduction	138	52	0.043
	Twigs	97	64	0.238
2008	Leaves	512	466	0.555
	Reproduction	116	85	0.508
	Twigs	109	125	0.688

Notes:
2005: d1 established in May because d3 was bulldozed
2007: d14a and d14b (DMPRC plots) were bulldozed Aug-Oct so missing data on these plots until we could get in and re-establish plots next to old plots at the end of Oct.

Table 8. Composition of nutrients content (g m^{-2} yr^{-1}) in litterfall biomass estimates on control and DMPRC plots located in Ft. Benning, GA. (, * = significant difference at 0.05, 0.10 levels respectively).**

Year	Type	Control	Treatment	Pr > | t |
2005	Carbon	267.6	267.6	0.998
	Nitrogen	4.1	4.5	0.581
	Phosphorus	0.56	0.53	0.774
2006	Carbon	237.9	278.9	0.021**
	Nitrogen	3.1	3.8	0.241
	Phosphorus	0.45	0.58	0.046**
2007	Carbon	335.9	206.8	0.023**
	Nitrogen	3.8	2.9	0.085
	Phosphorus	0.69	0.46	0.136
2008	Carbon	356.6	323.9	0.591
	Nitrogen	5.2	5.7	0.629
	Phosphorus	0.78	0.67	0.559

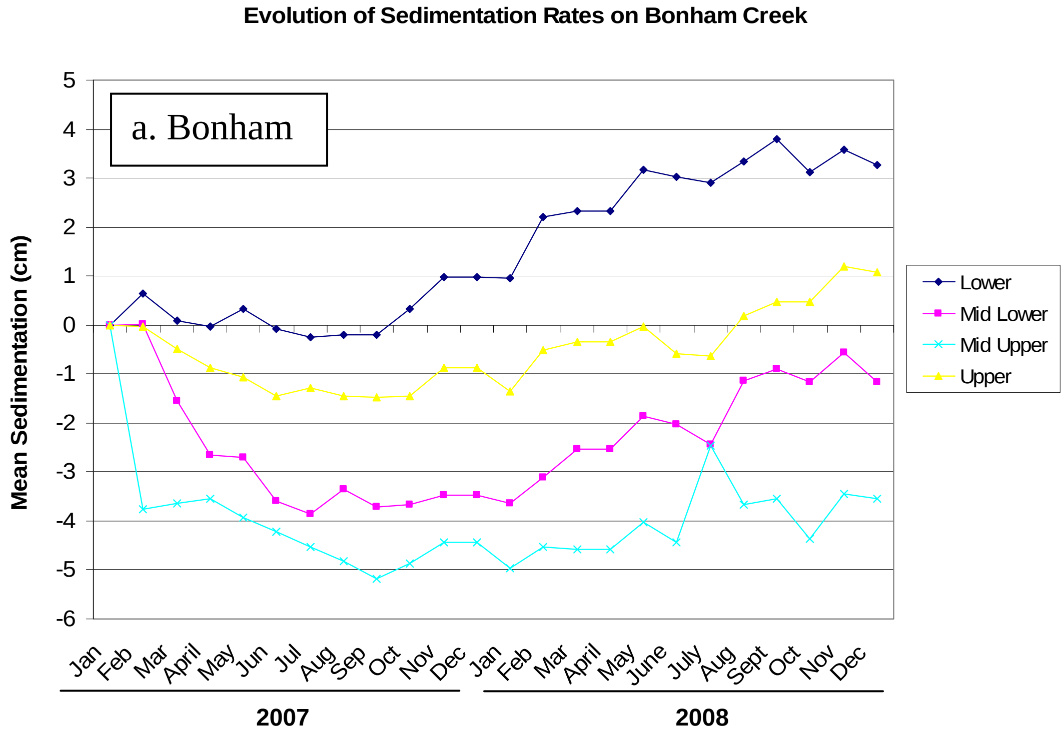
Notes:
2005: d1 established in May because d3 was bulldozed
2007: d14a and d14b (DMPRC plots) were bulldozed Aug-Oct so missing data on these plots until we could get in and re-establish plots next to old plots at the end of Oct.

Table 9. N:P ratios in litterfall control and DMPRC plots located in Ft. Benning, GA.

Year	Control	Treatment	Pr > |t|
2005	8.5	9.5	0.447
2006	7.0	7.8	0.355
2007	6.5	7.5	0.381
2008	7.5	8.5	0.381

Table 10. C:N ratios in litterfall control and DMPRC plots located in Ft. Benning, GA.

Year	Control	Treatment	Pr > |t|
2005	64	57	0.471
2006	72	66	0.584
2007	81	69	0.194
2008	62	55	0.285



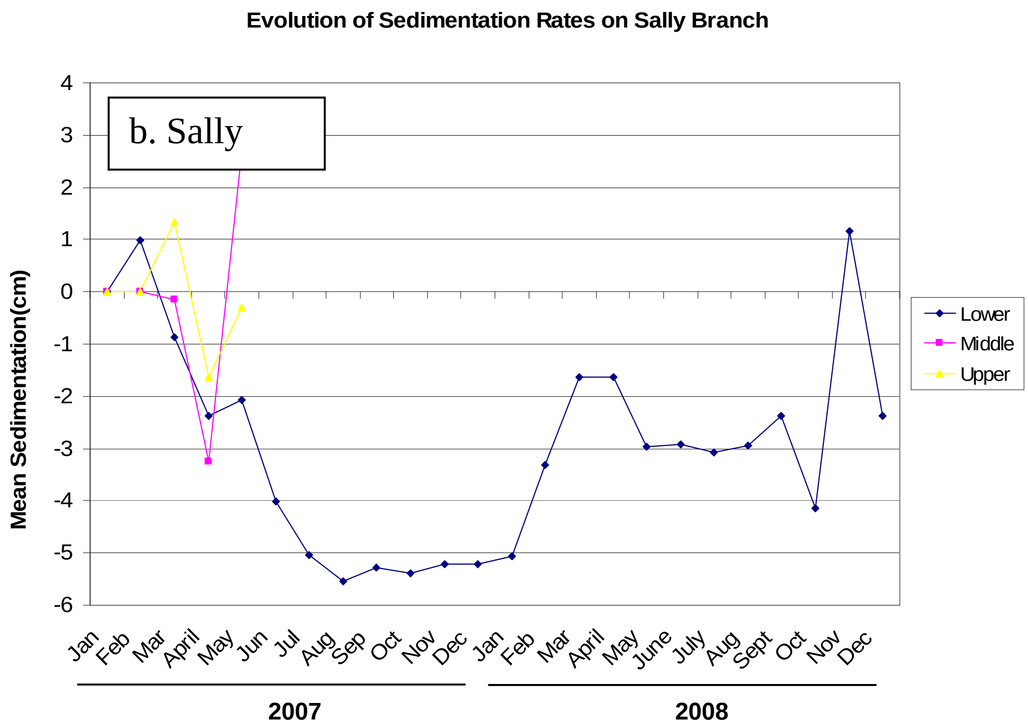


Figure 6. Mean sediment pin measurements for stream crossings at a) Bonham Creek and b) Sally Branch during 2007 and 2008 monitoring years, Ft. Benning, GA. Values are based on mean quadrant data for each crossing.

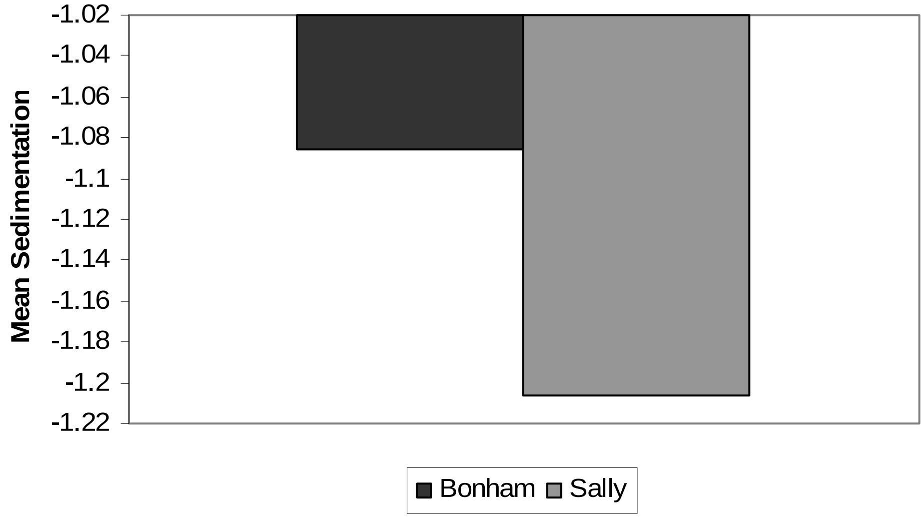


Figure 7. Average total streambank erosion on Bonham and Sally, Ft. Benning, GA.

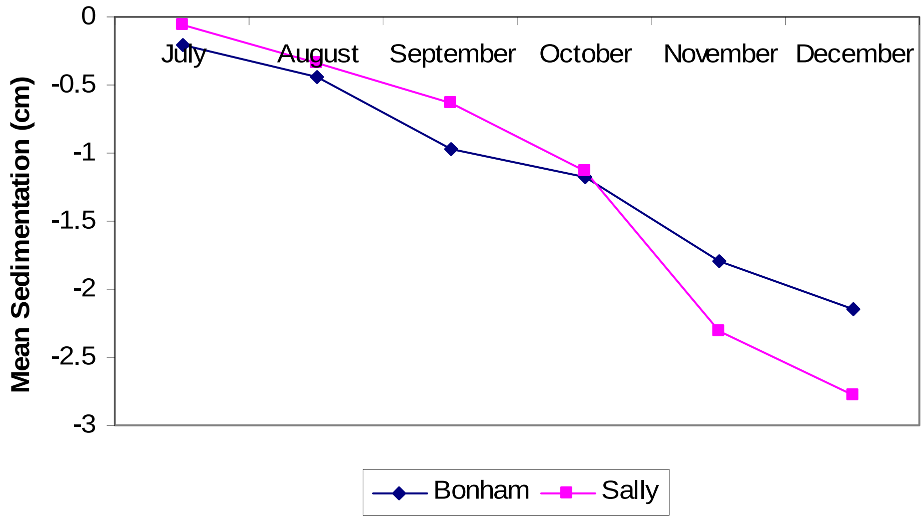


Figure 8. Mean streambank sediment pins measurements on Bonham and Sally, Ft. Benning, GA.

Summary

Little sediment movement occurred on the DMPRC plots and we suggest that conditions are likely to remain stable unless the integrity of the previously mentioned, vegetated zone is compromised. However, nitrogen mineralization rates were numerically (and significantly during one season in each of 06, 07, and 08) higher on DMPRC plots compared to controls. In contrast, microbial carbon and nitrogen were occasionally significantly higher on control plots. Mass, composition, and nutrient content of litterfall were generally similar between the two sets of plots apart from a few differences that we attribute to natural variation since no trend (statistical or numeric) was observed.

Sediment pin data from stream crossings reflected soil loss along banks of both streams. This is particularly noteworthy since these losses occurred during a period of very low rainfall and low stream flow. The fact that no consistent pattern of sediment loss / gain was observed regarding upstream or downstream positions relative to the crossings suggests that soil losses were not associated with stream flow. At Bonham Creek in particular, average sedimentation data indicated that 3 of 4 crossings could be characterized as sediment sources (net soil export) during the monitoring period. At Sally Branch, erosion data showed more variability although crossings there were predominantly sources rather than sinks as well.

Much of the 2007 sampling took place under a severe drought. However, rainfall amounts were much closer to the 30-yr average in 2008. The lack of runoff during the 2007 period undoubtedly contributed to a low potential for sediment movement. In addition, increased mortality of some of the herbaceous vegetation that has enhanced site roughness (and stability) was observed. There was some concern in 2007 that erosion would be stimulated once normal rainfall patterns returned, but this did not prove to be the case in 2008.

In general, the terrestrial biogeochemical influences of the DMPRC were minimal apart from erosion associated with stream crossings in the two years following crossing construction. Based on observations made during that period, there seemed to be a temporal disconnect between crossing construction and the implementation of soil stabilization measures. We recommend that these two processes, i.e. construction and stabilization, be linked much more closely in time during future operations.

Also, DMPRC construction stimulated nitrogen mineralization on those plots. This is a common occurrence after forest disturbance and is one of the mechanisms through which vegetation occupancy and succession are facilitated. Given the nitrogen deficient nature of the upland forests at Ft. Benning, it is important to re-vegetate disturbed areas as soon as possible in order to prevent soil nitrogen losses which might impact future forest productivity.

STREAM HYDROLOGY AND WATER QUALITY

Assessment of DMPRC impacts on stream hydrology involved development of stage-discharge rating curves for the Bonham Creek and Sally Branch ECMI stations where stage records were available. These stations are at or very near our downstream sampling stations. We then use these rating curves to develop discharge records for these streams. To evaluate impacts on hydrology we computed storm recession constants (4-hour) over the three-year period prior to DMPRC construction and compare these with storm recession constants after initiation of DMPRC construction. Storm recession constants are a good metric of stream hydrograph "flashiness" and our previous studies have shown an increase in stream flashiness with increasing disturbance level (Maloney et al. 2005).

We were able to develop reasonably good rating curves for Bonham Creek and Sally Branch (Fig. 9). Repair of the culvert at the Sally Branch station in August 2005 appeared to have resulted in a change in the stage-discharge relationship and we used slightly different relationships for the period before and after August 2005.

Based on the 4-hour storm recession constant data, there is evidence of an increase in hydrologic flashiness in both Sally Branch (Fig. 10) and Bonham Creek (Fig. 11). In both streams, 4-hour storm recession constants increased significantly after forest clearing and initiation of construction in September 2004. These results are not surprising because it is well known that deforestation results in an increase in hydrograph flashiness, with higher peak flows and steeper flow recession slopes, and a considerable portion of the Sally Branch and Bonham Creek watersheds were deforested. We were unable to obtain stage records for these streams after 2006 because the data were not downloaded from the field on a regular basis as part of the ECMI program after 2006.

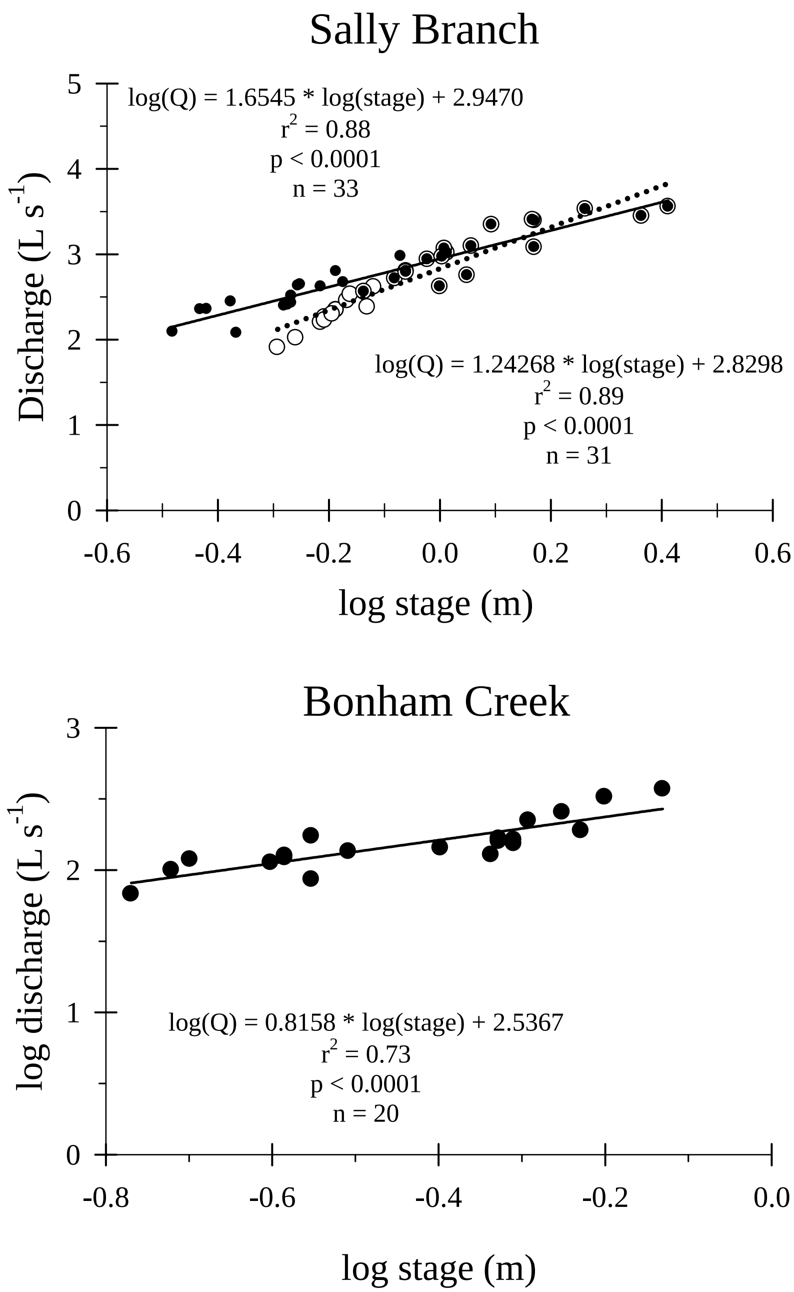


Figure 9. Stage-discharge relationships for Sally Branch and Bonham Creek at or near the downstream sampling stations. Open symbols in the upper plot for Sally Branch are for the period after August 2005 and closed symbols for the period before August 2005.

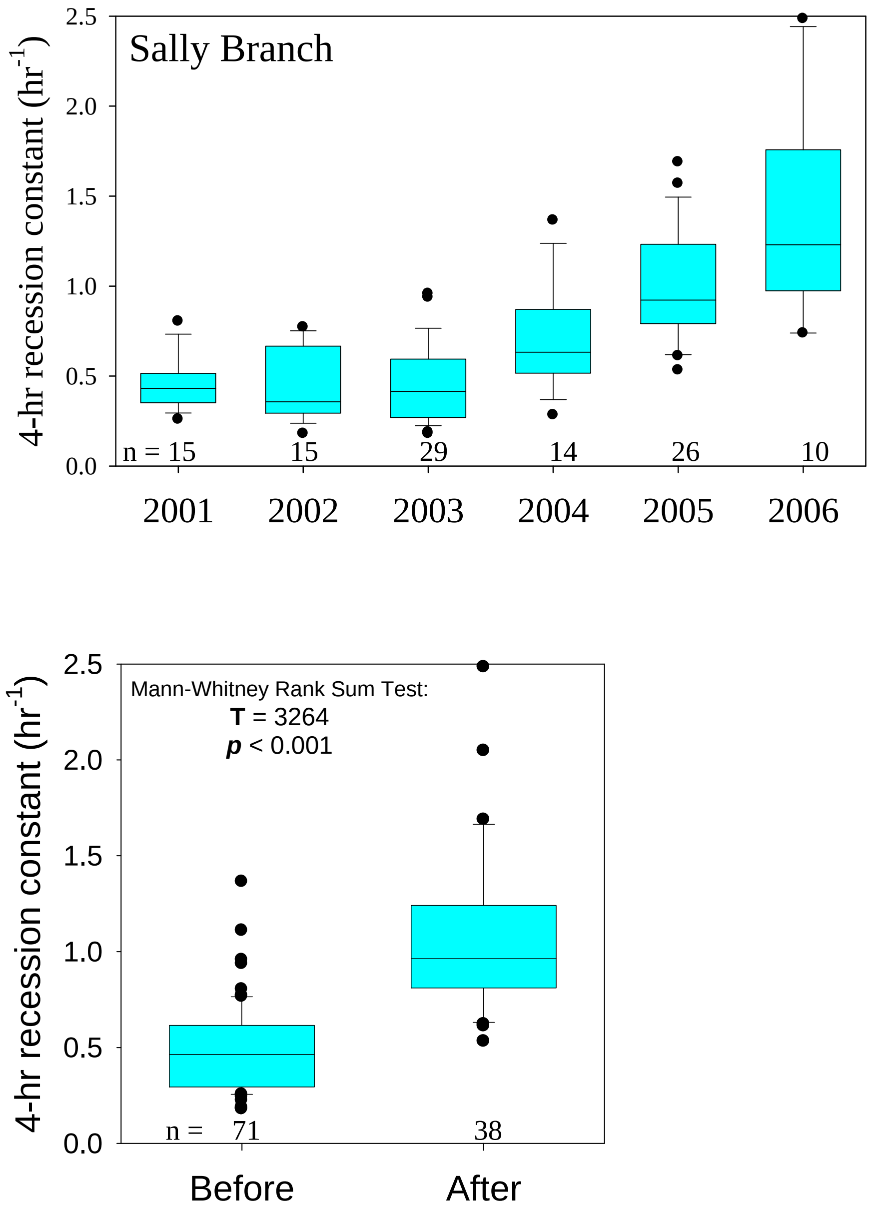


Figure 10. Box and whisker plots of 4-hour storm recession constants for Sally Branch by year (upper panel) and grouped into the period before (2001-2003) and after (September 2004 through 2006) DMPRC construction (lower panel). There was a statistically significant increase in the storm recession constants after construction began (lower panel).

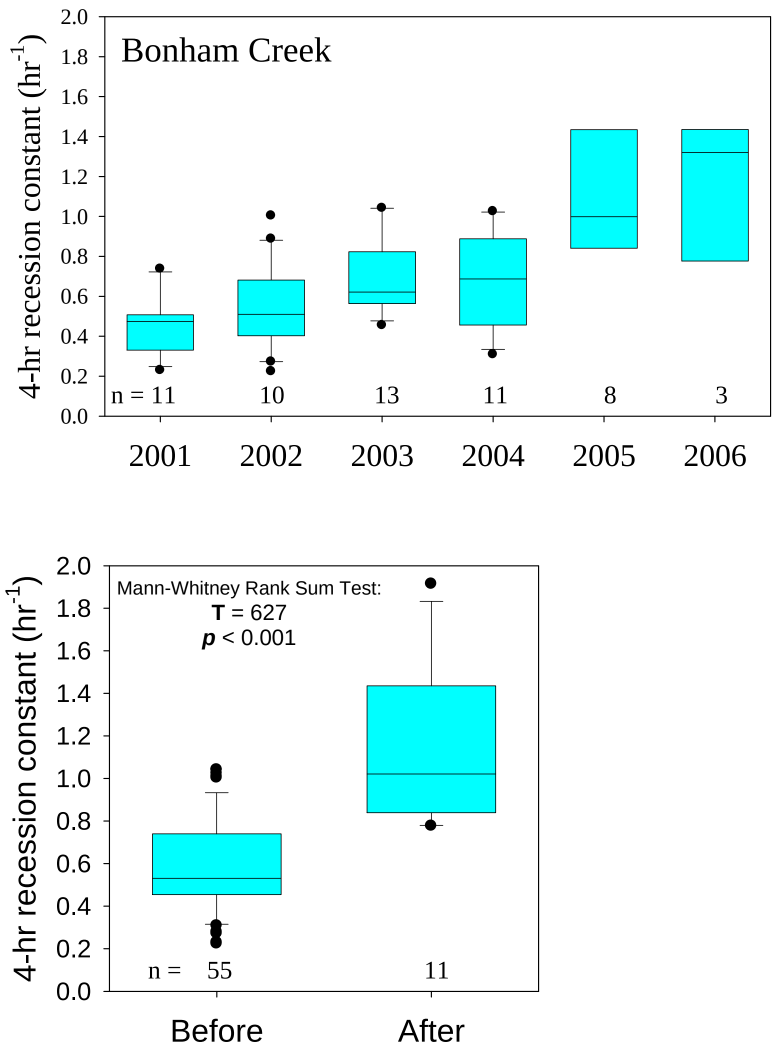


Figure 11. Box and whisker plots of 4-hour storm recession constants for Bonham Creek by year (upper panel) and grouped into the period before (2001-2003) and after (September 2004-2007) DMPRC construction (lower panel). There was a statistically significant increase in the storm recession constants after construction began (lower panel).

Assessment of DMPRC impacts on stream water quality involved grab sampling at 3-6 week intervals (mostly representing baseflow conditions) and sampling during stormflow events during different times of the year. Analyses performed on grab samples included water temperature, specific conductance, pH, suspended sediment concentrations (total, inorganic, organic), and concentrations of dissolved organic carbon (DOC), ammonium (NH4), nitrate (NO3), soluble reactive phosphorus (SRP), These analyses are performed using standard techniques described in Houser et al. (2006).

The primary DMPRC impacts on water quality observed to date are sharp increases in suspended sediment concentrations in Bonham Creek and its tributary (D13)

observed in both grab sampling and storm samples. Although elevated total suspended sediment (TSS) concentrations were observed in Bonham Creek grab samples after forest clearing in late 2004 and early 2005, high baseflow TSS concentrations (30 to 40 mg/L) have been commonly observed since early 2006 (Fig. 12, top panel). In D13, very high TSS values (30 to 100 mg/L) were consistently observed in 2006 and 2007 (Fig. 12, lower panel). These impacts in the Bonham Creek watershed appear to coincide with construction activities in close proximity to the streams, including installation of culverts at road crossings. There appears to be an indication that TSS concentrations have declined since late 2006 in Bonham Creek (and since late 2007 in the Bonham Creek tributary, D13), perhaps because construction activities near streams have been curtailed. In contrast to the situation in Bonham Creek, TSS concentrations in Sally Branch have generally remained low and similar between upstream and downstream sites, indicating minimal impacts of DMPRC construction on TSS concentrations during baseflow periods in this stream (Fig. 12, middle panel).

Concentrations of TSS during storms in Bonham Creek and D13 also show a sharp increase in sediment loading in late 2005 and 2006. TSS concentration increases in Bonham Creek during three storms in early 2005 (after forest clearing but prior to construction) remained relatively moderate (peak concentrations of <100 to 200 mg/L). However, TSS increases were much larger in Bonham during four storms sampled from November 2005 through May 2006, with peak values of 1000 to >4000 mg/L (Fig. 13). Interestingly, the decline in TSS concentrations during baseflow observed after late 2006 in Bonham (Fig. 12) are not also observed in the storm TSS data record, indicating continuing DMPRC impacts on sediment inputs and transport. Similarly, in D13, increases in TSS concentrations during several storms in late 2005, 2006, and 2007 were very large (1000-1500 mg/L) and considerably higher than TSS increases during six storms in 2004 (prior to forest clearing) and during the first half of 2005 (after clearing but prior to large-scale construction activities)(Fig. 14). Until April 2007, there was no evidence of significant increases in sediment loading during storms in Sally Branch as storm TSS concentration increases were relatively moderate (<100 to 300 mg/L) (Fig. 15). However, TSS concentrations increased to much higher levels in a storm in April 2007 (to about 2000 mg/L), perhaps reflecting more intensive construction activities in the Sally Branch watershed.

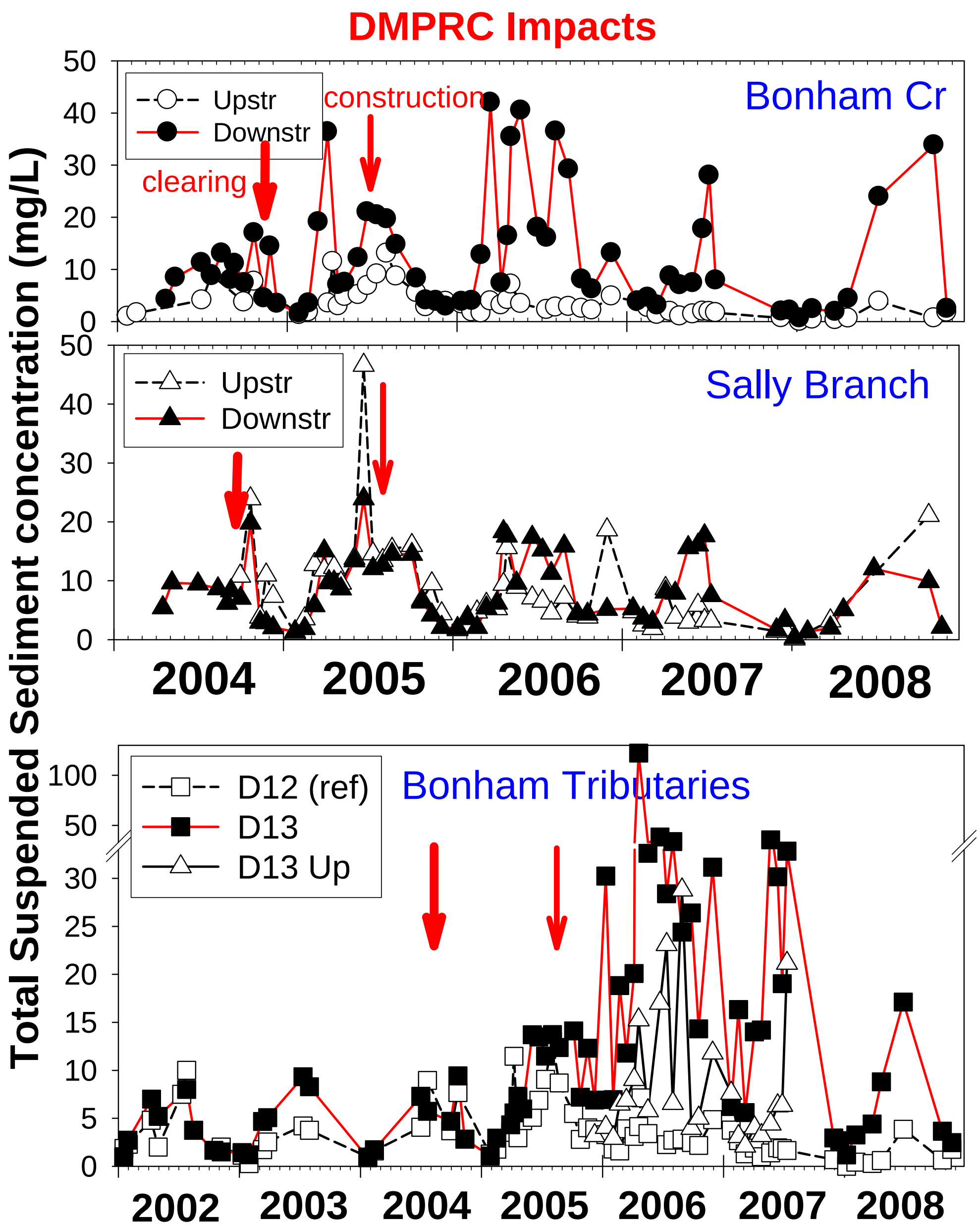


Figure 12. Total suspended sediment (TSS) concentrations in grab samples from upstream or reference sites (open symbols) and downstream sites (solid symbols) potentially impacted by DMPRC construction in Bonham Creek (top panel), Sally Branch (middle panel) and a tributary of Bonham Creek, D13 (lower panel). Initiation of forest clearing and DMPRC construction activities are shown by the vertical red arrows.

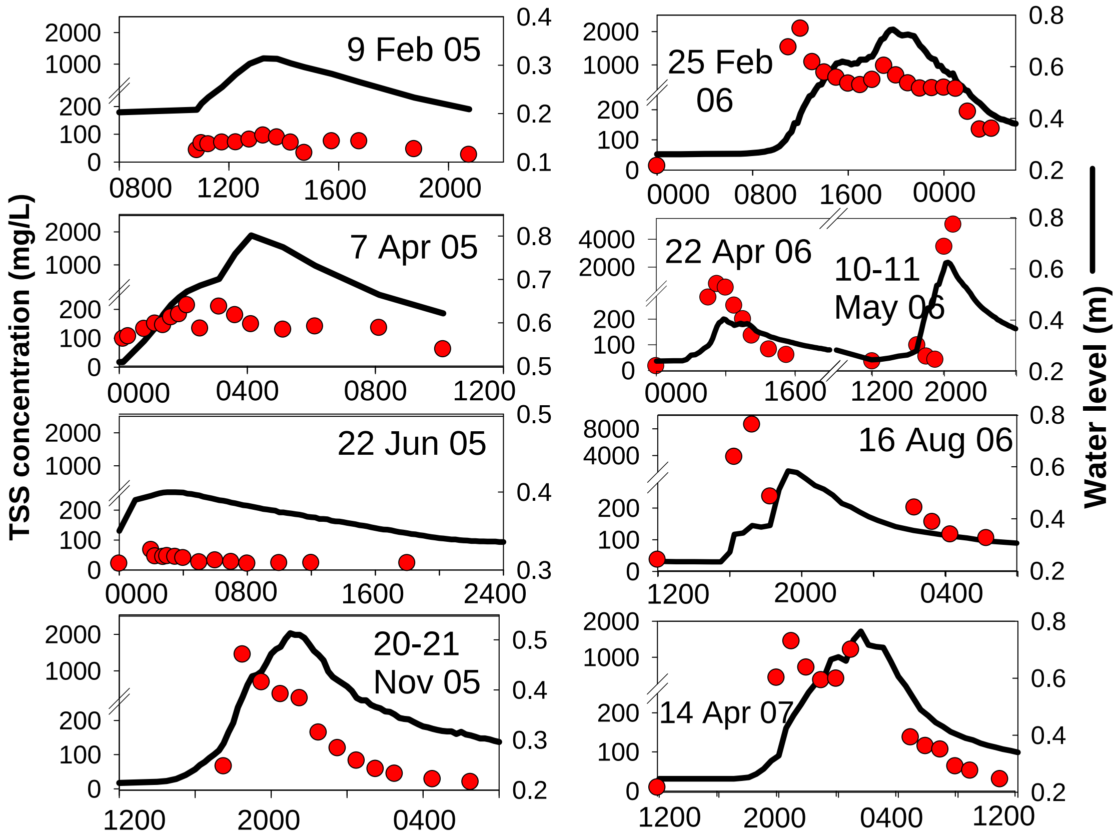


Figure 13. Hydrographs (solid lines) and total suspended sediment (TSS) concentrations (red circles) during several storms in Bonham Creek. The upper left 3 panels cover the period after forest clearing but prior to large-scale construction activities (storms in Feb, Apr, and Jun 2005). The remainder of the panels (the 20-21 Nov 05 storm and afterward) are after large-scale construction activities were initiated, including road crossings and installation of culverts.

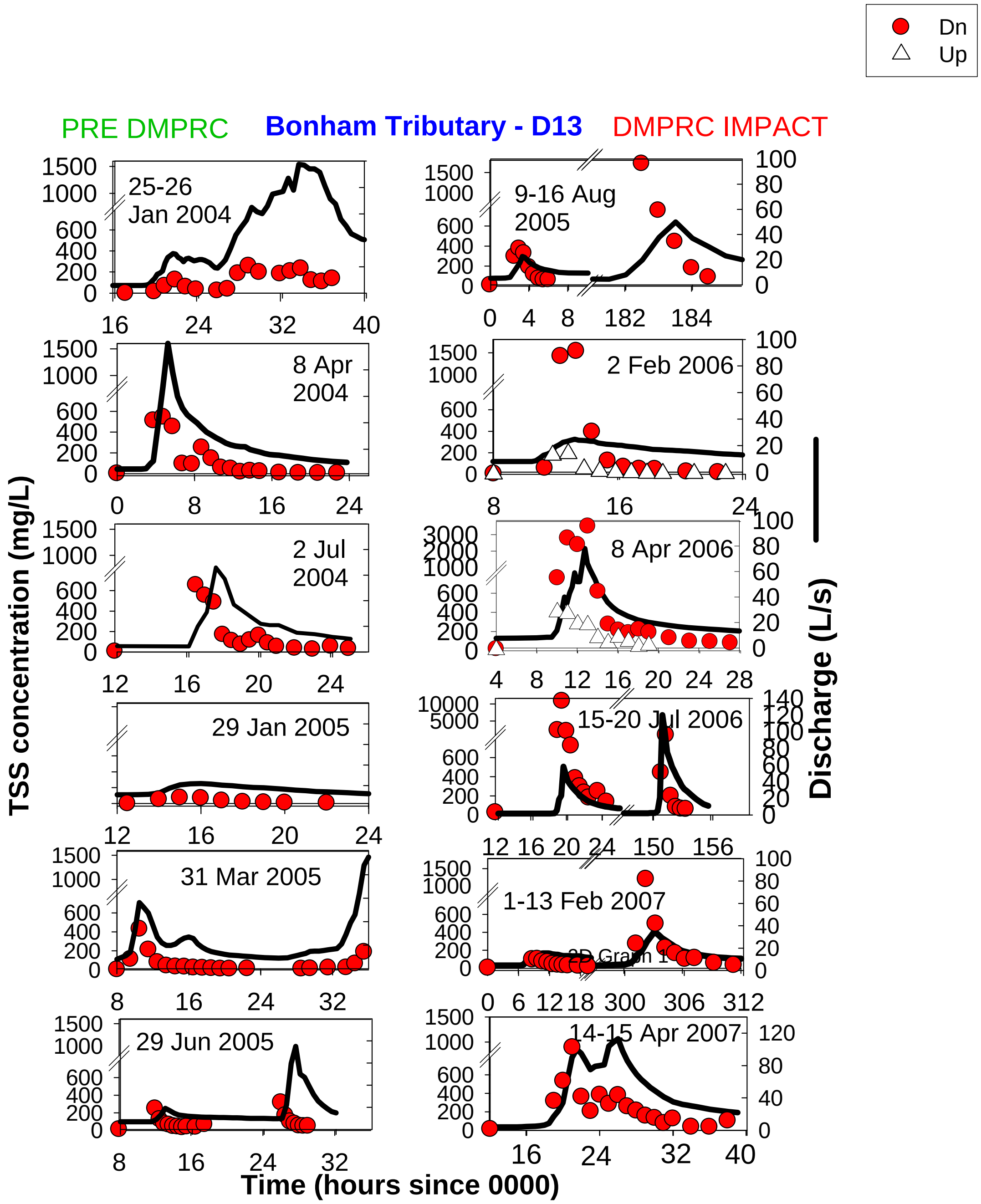


Figure 14. Hydrographs (solid lines) and total suspended sediment (TSS) concentrations (red circles) during several storms in the Bonham Creek tributary, D13. The left set of panels cover the period prior to DMPRC construction and the right set of panels are after large-scale construction activities began, including road crossings and installation of culverts.

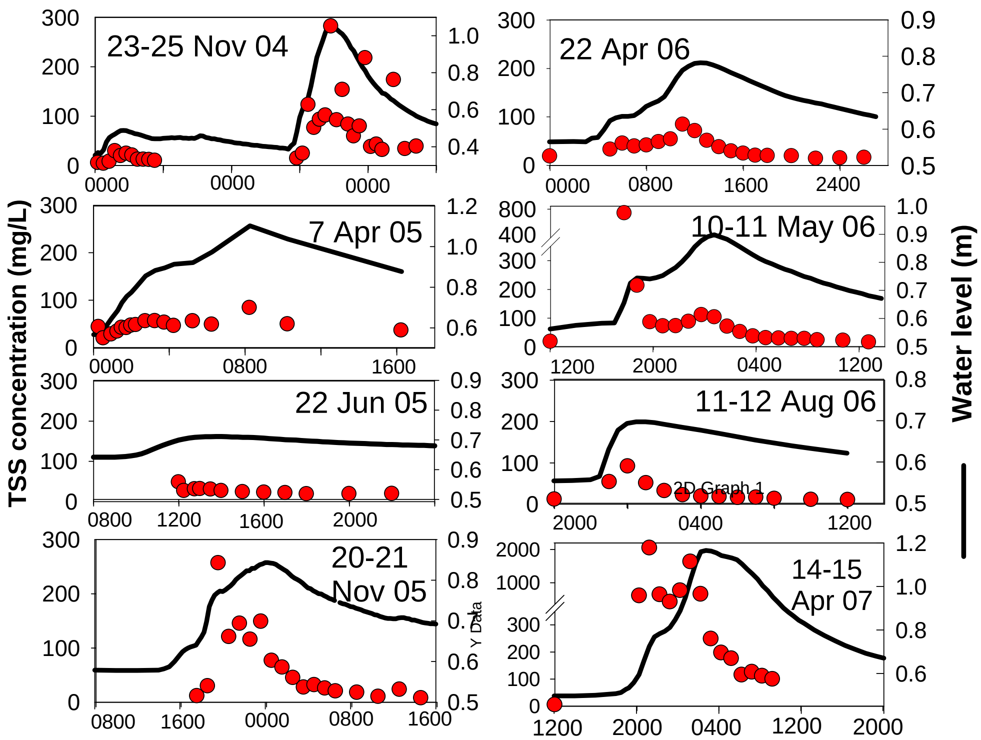


Figure 15. Hydrographs (solid lines) and total suspended sediment (TSS) concentrations (red circles) during several storms in Sally Branch. The 3 panels in the upper left of the figure are for the period after forest clearing but prior to large-scale construction activities. The remainder of the panels are after large-scale construction activities were initiated in mid 2005.

Another way to show the trends in storm TSS concentrations in these streams is to plot the maximum storm TSS concentrations over time. In our originally-funded SERDP project on impacts of disturbance on streams, we showed that maximum storm TSS concentrations increased sharply with an increase in the percentage of the catchment highly disturbed by unpaved roads and vehicle maneuver areas. Plots of the maximum storm TSS concentrations in each of the DMPRC study streams shows that significant impacts of construction have been observed in all streams (Fig 16.). In Bonham Creek and the D13 Bonham Creek tributary, sharp increases in maximum storm TSS concentrations were observed in mid 2005, just after construction activities began. In Bonham Creek, maximum storm TSS concentrations continue to be substantially elevated during some storms in 2007 and 2008. However, maximum storm TSS concentrations in the D13 tributary (Fig. 16, lower panel) appear to have declined in 2007 and 2008, indicating reduced (but still evident) impacts of DMPRC on sediment input and transport in this stream. The situation in Sally Branch was somewhat different than in Bonham Creek. Sharp increases in storm TSS concentrations were generally not been observed in Sally Branch until spring 2007, probably due to an increase in construction activity or

more construction activity near the stream at this time. Maximum TSS concentrations during some storms continue to be substantially elevated in Sally Branch in 2008.

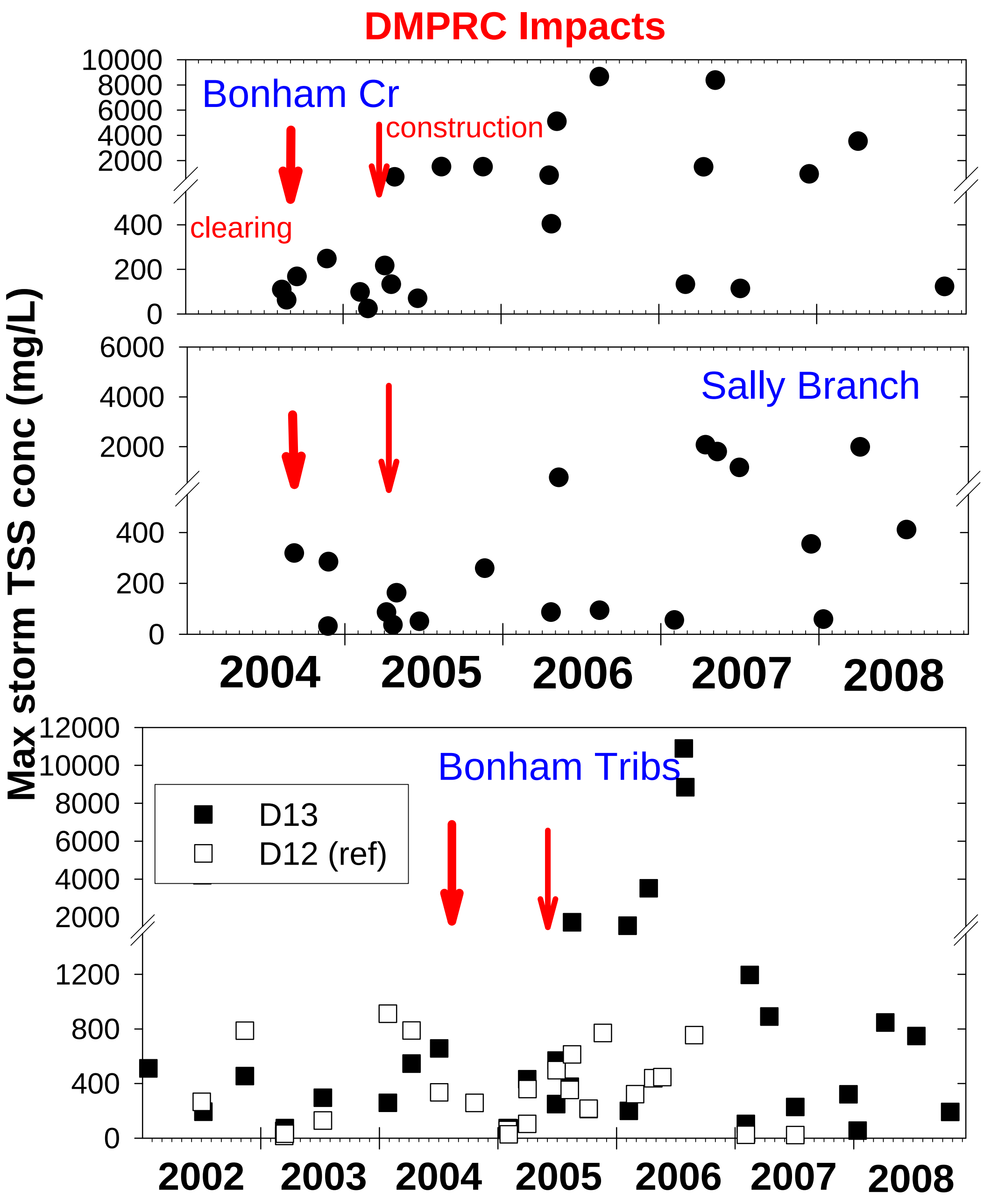
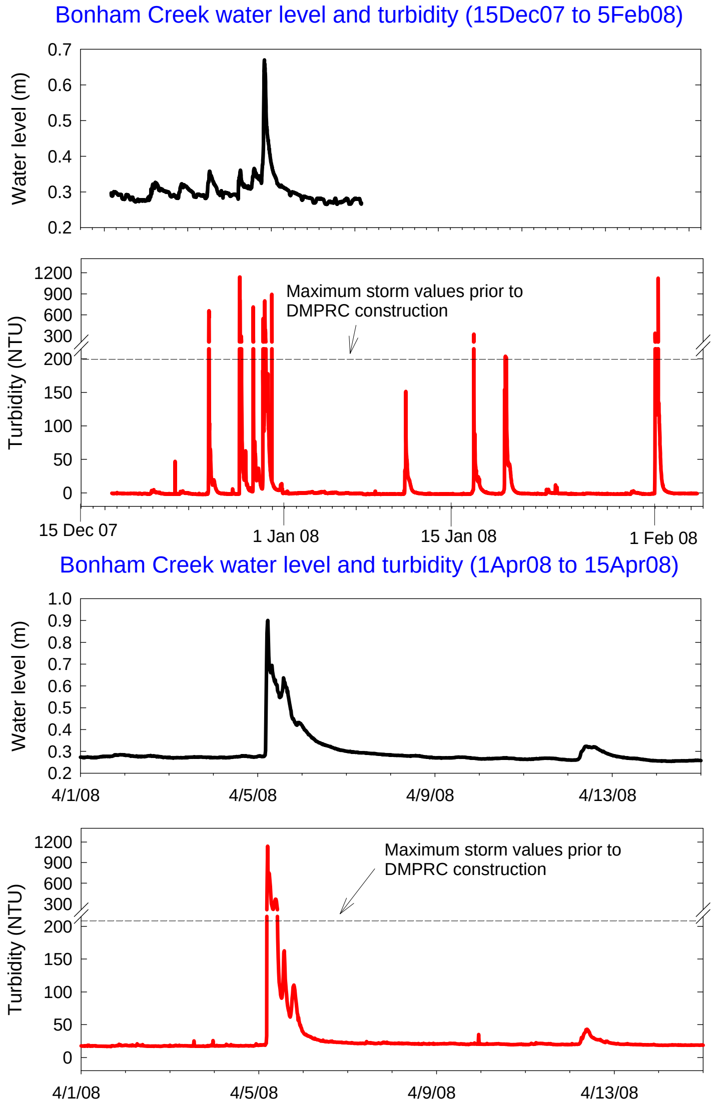


Figure 16. Maximum suspended sediment (TSS) concentrations during storms in Bonham Creek (top panel), Sally Branch (middle panel) and a tributary of Bonham Creek, D13, and a nearby reference stream, D12 (lower panel). Initiation of forest clearing and DMPRC construction activities are shown by the vertical red arrows.

Beginning in late 2007, continuous measurements of stream stage and turbidity (YSI optical sensors) were made during several 4- to 8-week campaigns in Bonham Creek and Sally Branch to provide more robust observations of short-term variations in TSS concentrations during storms. The results of these observational campaigns are presented in Figs. 17 and 18. Peak TSS concentrations for storms in 2008 continued to be elevated in Bonham Creek and Sally Branch relative to pre-DMPRC values, with maximum TSS concentrations of from 500 to 1000 mg/L or higher. Peak TSS concentrations for the last set of storms sampled in October and November 2008 were relatively low (< 200 mg/L) and may indicate that erosion and sediment controls are finally resulting in a reduction in sediment input and transport resulting from DMPRC construction. However, winter and spring storms have been the most problematic for sediment inputs (highest storm TSS concentrations) and it remains to be seen whether erosion and sediment controls have significantly reduced storm TSS concentrations during these periods in Bonham Creek and Sally Branch.



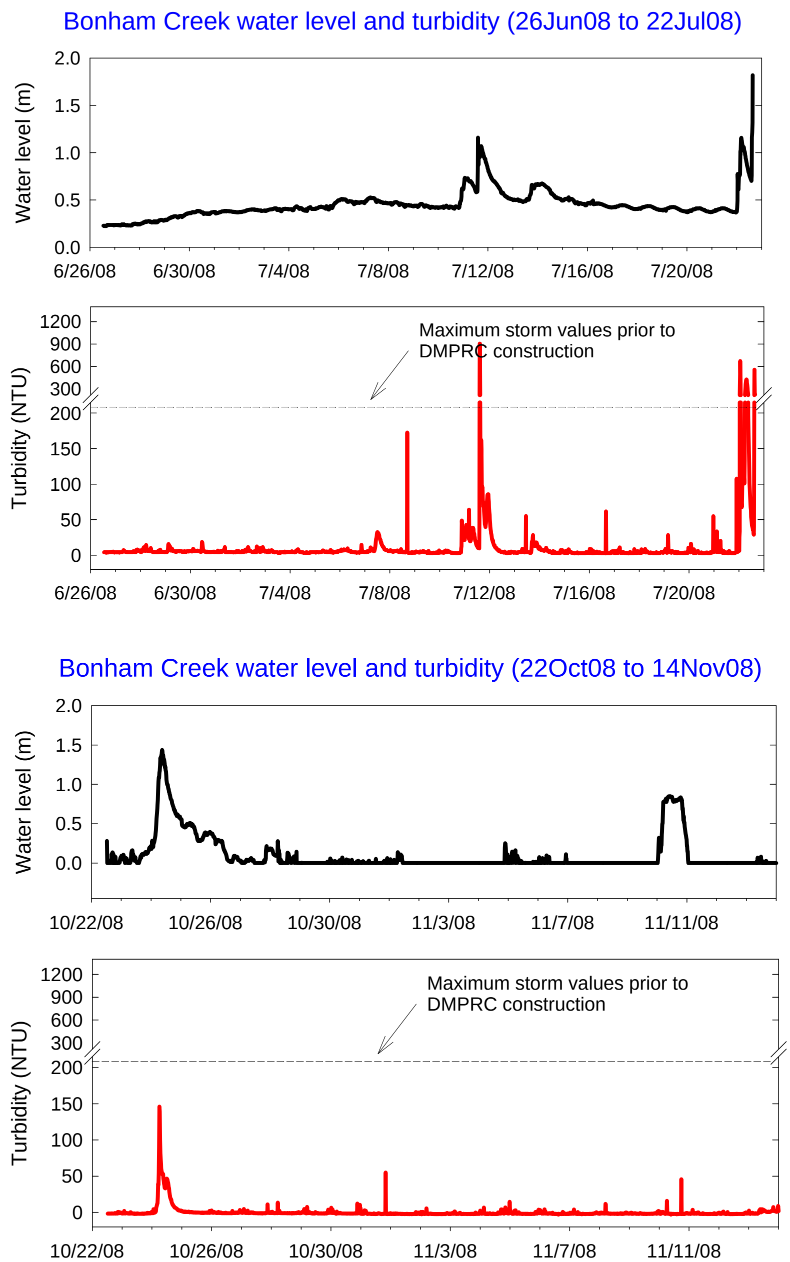
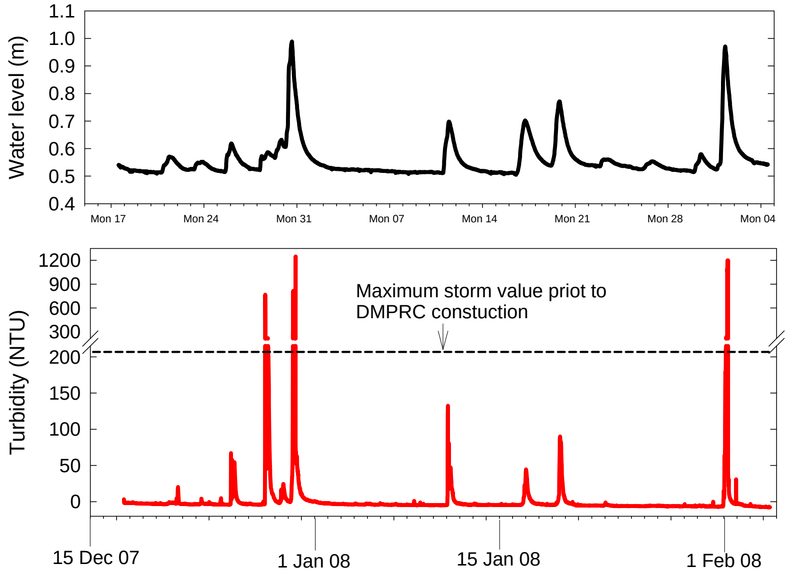
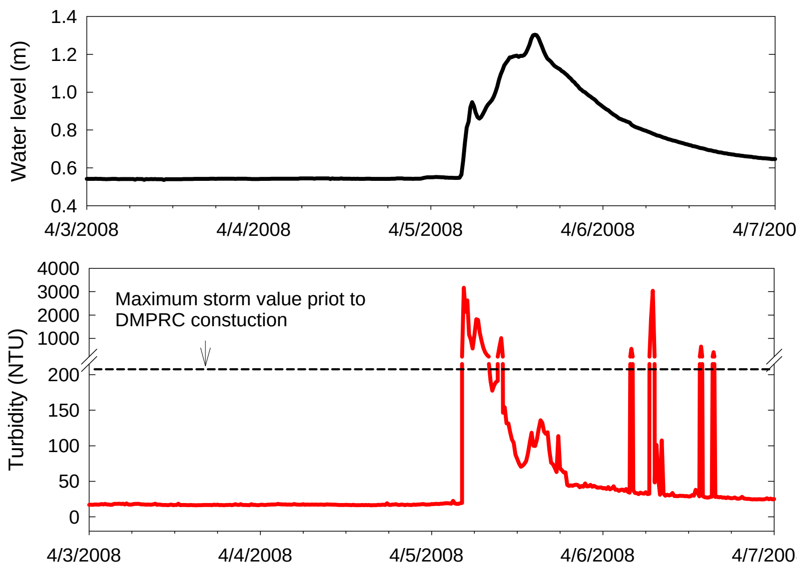


Figure 17. Records of water level and turbidity at 15-min intervals for extended periods in Bonham Creek beginning in December 2007.

Sally Branch water level and turbidity (15Dec07 to 5Feb08)



Sally Branch water level and turbidity (3Apr08 to 8Apr08)



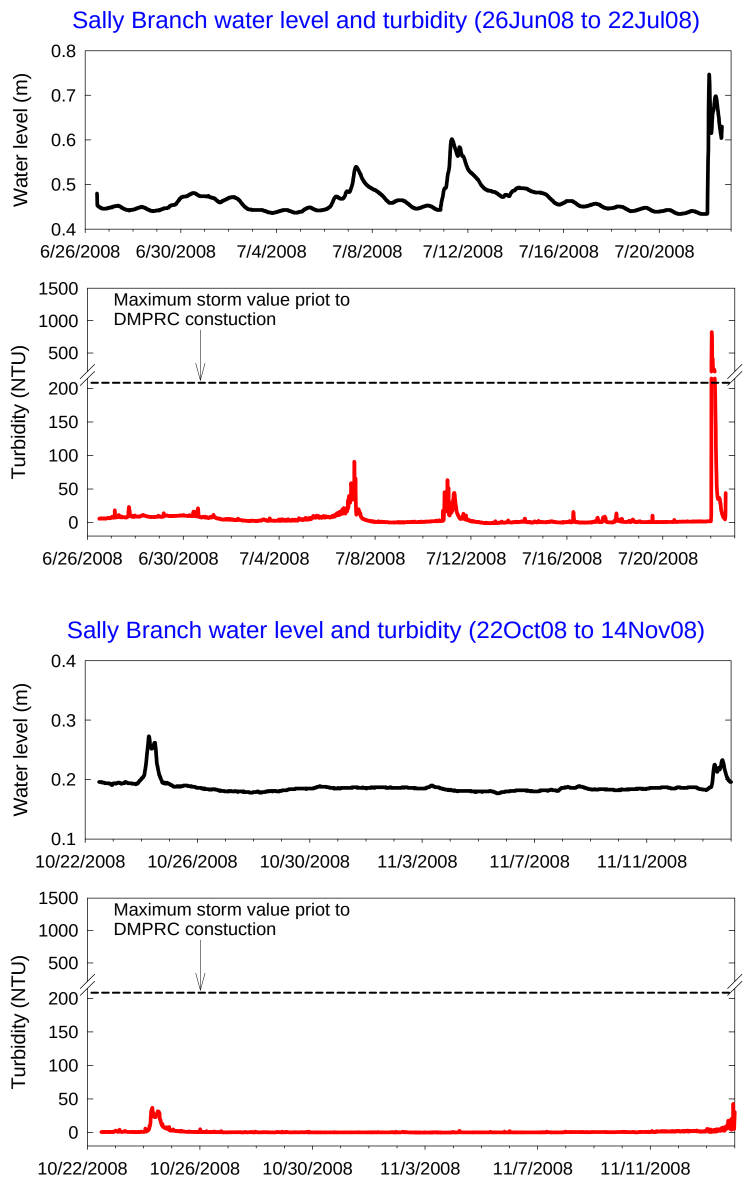


Figure 18. Records of water level and turbidity at 15-min intervals for extended periods in Sally Branch beginning in December 2007.

There appear to be increases in dissolved inorganic nitrogen (DIN, sum of NH_4 and NO_3) concentrations in Bonham Creek and D13 grab samples (mostly during baseflow) in 2006 (Fig. 19). However, these increases appear to have subsided in 2007 and 2008 and were not evident in Sally Branch at any time. The higher baseflow DIN concentrations in Bonham Creek and its tributary may reflect impacts (e.g., increased mineralization of soil organic N associated with disturbance) of intensive construction activities near the stream channel during this period. There was no evidence of construction impacts on stream PO_4 concentrations during baseflow periods in these streams, with concentrations remaining generally below 7 μgP/L.

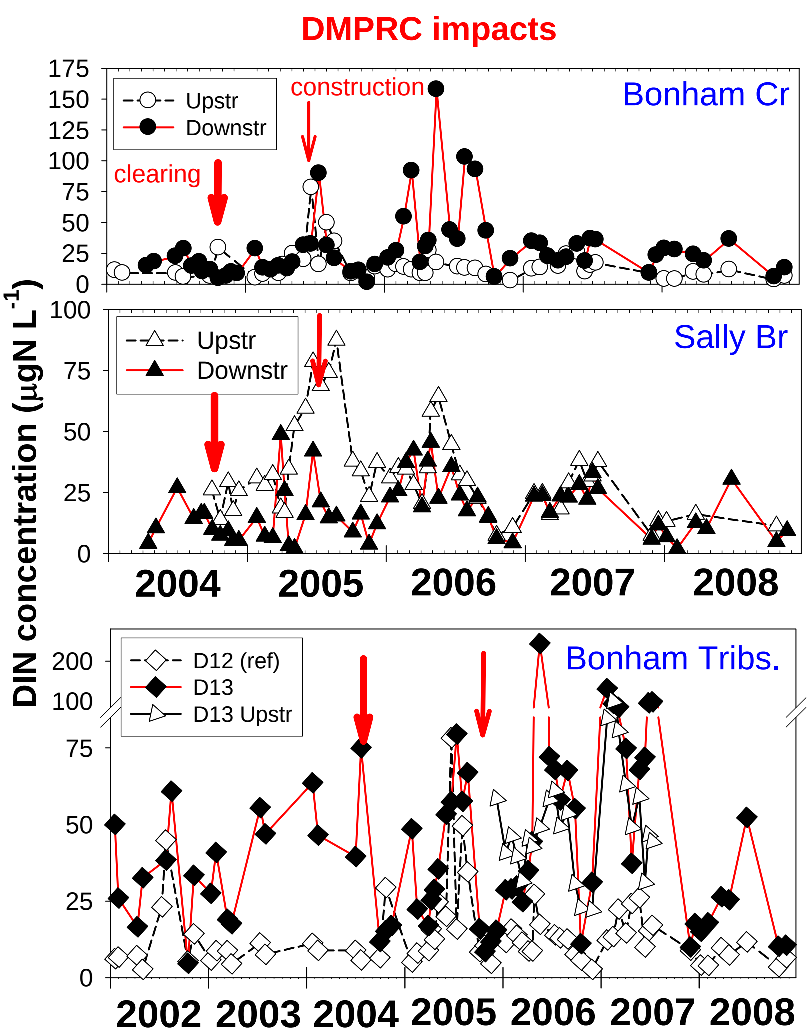


Figure 19. Dissolved inorganic nitrogen (DIN) concentrations in grab samples from upstream or reference sites (open symbols and dashed lines) and downstream sites (solid symbols and red lines) potentially impacted by DMPRC construction in Bonham Creek (top panel), Sally Branch (middle panel) and a tributary of Bonham Creek, D13 (lower panel). Initiation of forest clearing and DMPRC construction activities are shown.

Larger increases in DIN concentration during storms also indicate impacts of construction activities resulting in higher rates of N loss from the catchments drained by Bonham Creek, its tributary (D13), and Sally Branch. Typically, stream DIN concentrations increase somewhat during storm flow in Fort Benning streams, probably due to flushing of mineralized N from soils within the catchment. However, the DIN concentration increases in these streams during storms were greater after construction activities were initiated. For example, in Bonham Creek, maximum DIN concentrations during storm flows were considerably larger in 2006 compared with those during 2005 (Fig. 20).

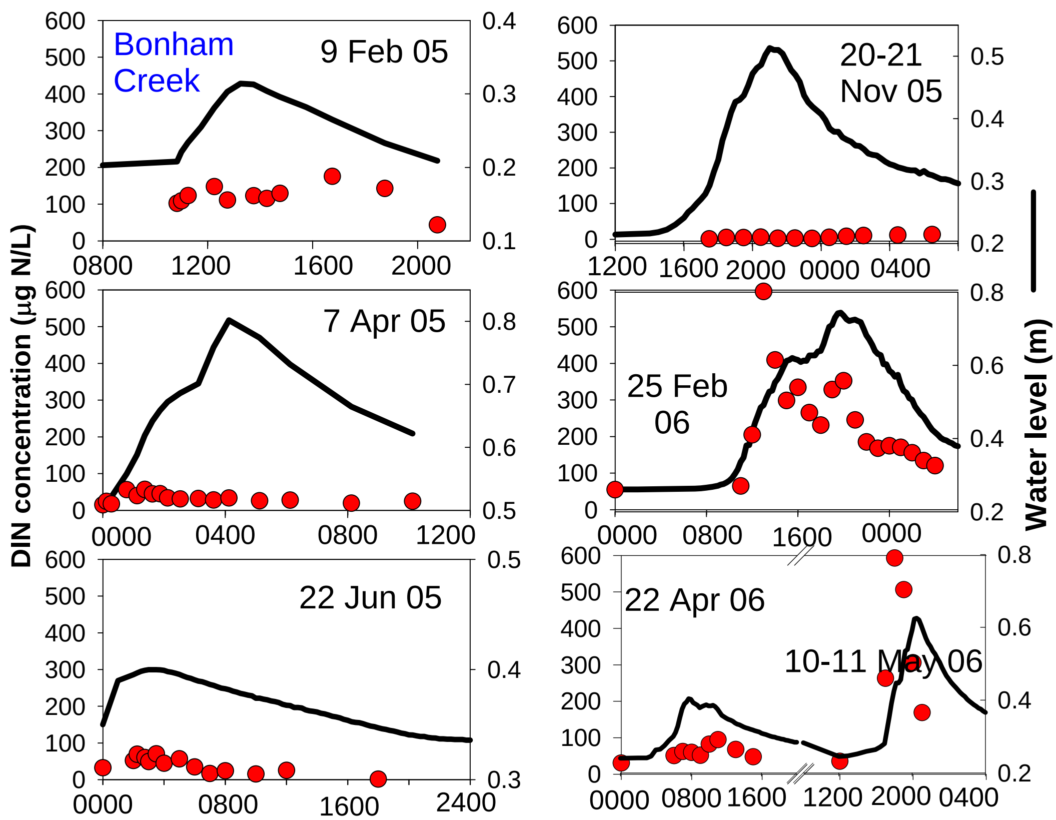


Figure 20. Hydrographs (solid lines) and dissolved inorganic nitrogen (DIN) concentrations (red circles) during several storms in Bonham Creek. The left set of panels cover the period after forest clearing but prior to large-scale construction activities. The right set of panels are after large-scale construction activities were initiated, including road crossings and installation of culverts.

Summary plots of maximum stream DIN concentrations during sampled storms prior to DMPRC construction and after construction began show the impacts of construction on N dynamics in these catchments (Fig. 21). In Bonham Creek, maximum storm DIN concentrations increased sharply in 2006 (maximum concentrations of 600 to 800 µgN/L) compared to previous years (maximum concentrations < 200 µgN/L), and the higher storm DIN concentrations appear to have continued through 2008 (Fig. 21, top

panel). Higher storm DIN concentrations did not occur in Sally Branch until 2007 and it appears that they also are continuing in 2008, although the low number of storms sampled in 2008 results in uncertainty (Fig. 21, middle panel). Increases in the maximum storm DIN concentrations in the Bonham tributary, D13, were relatively small following construction (maximum concentrations $\leq$ 400 µgN/L), indicating a smaller impact on catchment N dynamics (Fig. 21, lower panel). Maximum storm PO_4 concentrations also increased somewhat after DMPRC concstruction in all streams, but the increases were relatively small. Maximum storm PO_4 concentrations were in the range 5 to 13 µgP/L after construction compared to a range of 2 to 7 µgP/L prior to construction in these streams. The higher post-construction storm PO_4 concentrations are nonetheless still relatively low compared to other human impacts such as agriculture or urbanization.

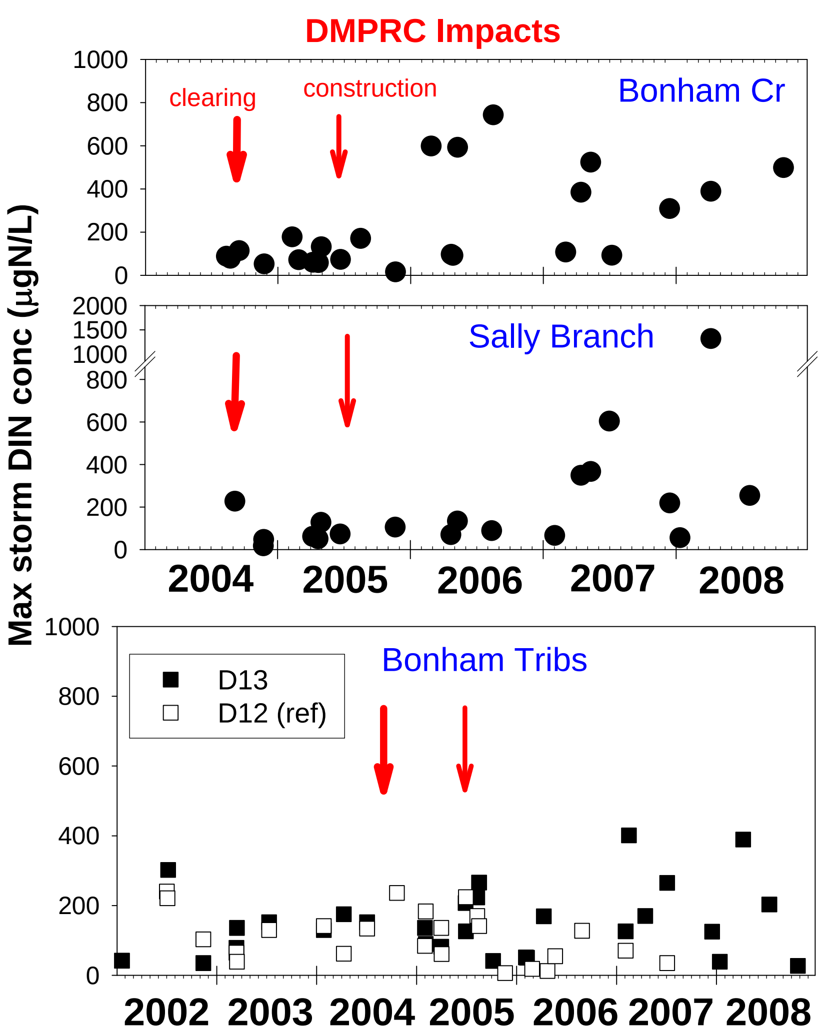


Figure 21. Maximum dissolved inorganic N (DIN) concentrations during storms in Bonham Creek (top panel), Sally Branch (middle panel) and a tributary of Bonham Creek, D13, and a nearby reference stream, D12 (lower panel). Initiation of forest clearing and DMPRC construction activities are shown by the vertical red arrows.

Reach-scale measures of metabolism have been measured in D13 and its reference (D12) since 2001. These measurements use the diurnal dissolved oxygen change technique to determine rates of gross primary production (GPP) and ecosystem respiration (ER). Experimental injections of propane are used to correct for oxygen exchange with the atmosphere. Measurements made through autumn 2005 did not show an effect of DMPRC construction on metabolism at D13 (Fig. 22). However, beginning in winter 2006, D13 began exhibiting significantly higher ER rates in each season (right panels). The observed ER increases in 2006 coincided with large sediment loading increases in this stream that began in early 2006 with the construction of a road crossing D13 about 200 m upstream of the metabolism reach. We were unable to continue the metabolism measurements in these streams after 2006.

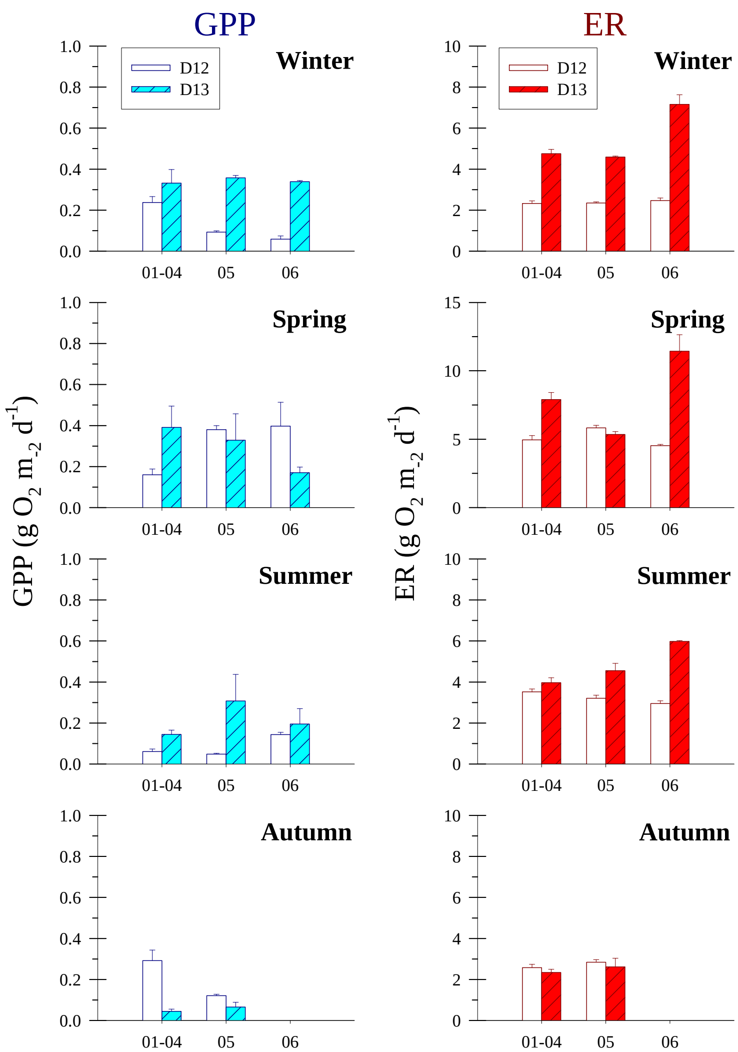


Figure 22. Gross Primary production (GPP, left panels) and ecosystem respiration (ER, right panels) rates both before (open bars) and after (shaded and hatched bars) DMPRC activities began for the winter (top panel), spring (second panel), summer (third panel), and autumn (bottom panel) sampling periods in D12 (reference stream) and D13 (DMPRC impacted stream). Rates were calculated using a single station whole stream diel DO change method. Individual bars are mean (+ SE) rates of individual sampling dates from the 3 or 4 (summer) years before restoration (open bars) and each of the 2 years after DMPRC activities began (shaded and hatched bars).

STREAM BIOTA AND BIOTIC HABITAT

Methods

Study Design

Data collection from the 3 downstream DMPRC and 3 upstream reference sites (in Sally Branch, Bonham Creek, and the Bonham Creek tributary [D-13]) involved measurement of several stream biotic and habitat variables during the project period (Table 11). Each measure was demonstrated in previous studies to be a useful indicator of catchment-scale disturbance at Fort Benning (Maloney et al. 2005, Maloney and Feminella 2006, Miller 2006, Maloney et al. 2006). Most sampling was done approximately seasonally (every 4 mo) over the study (i.e., spring, fall, and winter sampling), except for coarse woody debris and fish inventories, which were done annually (usually spring).

Table 11. Stream biotic and habitat variables measured for the DMPRC project.

Category	Measure/Variable	Method
Habitat	Benthic particulate organic matter (BPOM) abundance	Substrate cores
	Coarse woody debris (CWD) abundance	Cross-stream transects
	Streambed stability	Cross-stream transects
Biota-algae	Algal biomass (chlorophyll *a* concentration)	
	Diatom composition (% dominance of *Eunotia*)	Substrate cores
Biota-benthic macroinvertebrates	Total biomass, *H'*, total richness, % EPT, Georgia Multimetric Index (GAMMI), %Hydropsychidae/ % EPT GAMMI scores, relative abundance of Hydropsychidae taxa, relative abundance of *Leuctra*, Assemblage similarity (NMDS)	Surber sampling
Biota-fish (D-13)	Richness, abundance of dominant populations	Electroshocking

Our initial design involved comparing an upstream control-downstream impact site within each of the 3 study catchments. However, construction of a new stream-road crossing in the upper D-13 catchment in 2005 upstream of our reference sites precluded our use of this design for this catchment. Thus, our revised experimental design was to 1) use an upstream control-downstream impact comparison within each of Sally Branch and Bonham Creek catchments, and 2) compare changes in biotic/habitat measures in both Lower and Upper D-13 sites with pre-DMPRC conditions (i.e., prior to 2006) and post-DMPRC construction (e.g. comparing biota/habitat measures before vs. after new road construction). Long-term pre-DMPRC data were available for a study reach situated between Lower and Upper D-13 from the SERDP riparian project (CS1186), which allowed a more conventional pre- vs. post-DMPRC assessment in this catchment.

For analyses of benthic macroinvertebrate assemblages, we primarily used the Georgia Multimetric Index (GAMMI, GA Environmental Protection Division 2007), which was estimated for each stream site. GAMMI values were based on those from the Sandy Hills Level-IV Ecoregion (GAEPD, 2007). However, because of 1) high variation in availability of baseline data pre-DMRC among the 3 catchments, and 2) loss of sampling stations in some catchments during DMPRC construction, the 2 study catchments were analyzed with a different statistical design. For Bonham Creek and Sally Branch, pre-construction data (September 2004) were analyzed with *t*-tests comparing upper and lower sites. Sampling in Sally Branch was fit to accommodate a balanced repeated-measures ANOVA design to examine differences between upper and lower sites over time and a site–season interaction. In contrast, loss of some sampling stations during new road construction at Bonham Creek led to an unbalanced design among years during and after DMPRC construction, which prompted a factorial analysis and General Linear Model (GLM) approach (Zar 1999) to examine differences between upper and lower sites, among years and seasons, and interactions among these factors before and after construction. In addition, we used standard benthic community measures (i.e., Shannon's *H*', total richness, total biomass, and % EPT) and community ordinations (using nonmetric multidimensional scaling, NMDS), to supplement GAMMI results for Bonham Creek and Sally Branch.

In contrast, the availability of long-term benthic data for D13 from the SERDP riparian project (CS1186) allowed quantitative comparison of temporal differences in GAMMI scores from 4 years before DMPRC construction (2000 – 2004) to 4 years post-construction (2005–2008). In this case, analysis with GLM only was conducted for summer samples as it was the only season with representative benthic samples for all 8 years.

Results and Discussion

Streambed stability

Using the streambed stability measure, sites in Lower and Upper Bonham and Upper and Lower Sally Branch showed degrading (downcutting) channels over the study, whereas conditions in Upper and Lower D-13 varied over time (Fig. 23 A-C). Bonham degraded ~0.1 m over the 2.5-y study (0.04 m/y), with no significant differences in degradation between upper and lower sites over the study (p=0.395). Degradation was comparatively less in Sally Branch (~0.16 m/y), with a slight increase in scour in the lower site from May 2007 to May 2008 but with no change in the upper site during this period (Fig. 23 B&C). Like Bonham, scour in Upper and Lower Sally Branch did not differ over the 2.5-y study (p=0.246). Initially, Upper D13 revealed an aggrading (filling) channel in May 2006, which potentially resulted from sediment inputs from the spring 2005 DMPRC stream-road crossing immediately upstream of this site (Fig. 23A). Aggradation persisted through May 2007(Fig. 23B), but by May 2008 the channel in both upper and lower sites indicated degradation as upstream sediment sources decreased and on-site bed sediment was transported further downstream (Fig. 23C). Over the study, downcutt channels in all sites indicated no obvious sediment impacts from DMPRC

construction in the 3 catchments. Increased streambed height from sediment accumulation, appeared to be limited to the D-13 catchment and for only 1 to 2 y following road construction.

Abundance of Instream Coarse Woody Debris

Although somewhat variable, the amount of submerged coarse woody debris (CWD) in the stream channel, a measure of habitat quality for benthic macroinvertebrates and fishes, generally increased in most sites over the study (Fig. 24). From Oct 2004 to May 2008 CWD increased 4- and 5-fold in Lower and Upper Bonham, respectively, 4- and 2-fold in Lower and Upper Sally Branch, respectively, and 3-fold in Upper D-13. Only in Lower D-13 was there no increase in CWD abundance (Fig. 24). Given there was a general increase in CWD abundance across 5 of the 6 sites (83%), there were no discernable impacts from DMRPC construction that led to a reduction in this benthic habitat during the study.

Increases in submerged CWD from 2004 to 2008 in most sites likely resulted from changes in the hydrologic regime over the study and its influence on instream CWD. The water years 2004 and 2005 were among the wettest years on record (e.g., 2nd and 4th wettest summer in 60 y), whereas 2006, 2007, and 2008 all were normal precipitation or dry years (unpublished data). High rainfall and discharge in 2004 and 2005 may have lowered instream CWD, and normal or low-discharge conditions in subsequent years may have allowed CWD accumulation in all sites except Lower D-13 (Fig. 24). Beyond natural factors, increased instream CWD in Upper D-13 also may have resulted from increased riparian wood inputs to the stream channel following timber harvesting during DMPRC construction, although our study was not designed to differentiate between natural vs. construction-based sources of changes in CWD input.

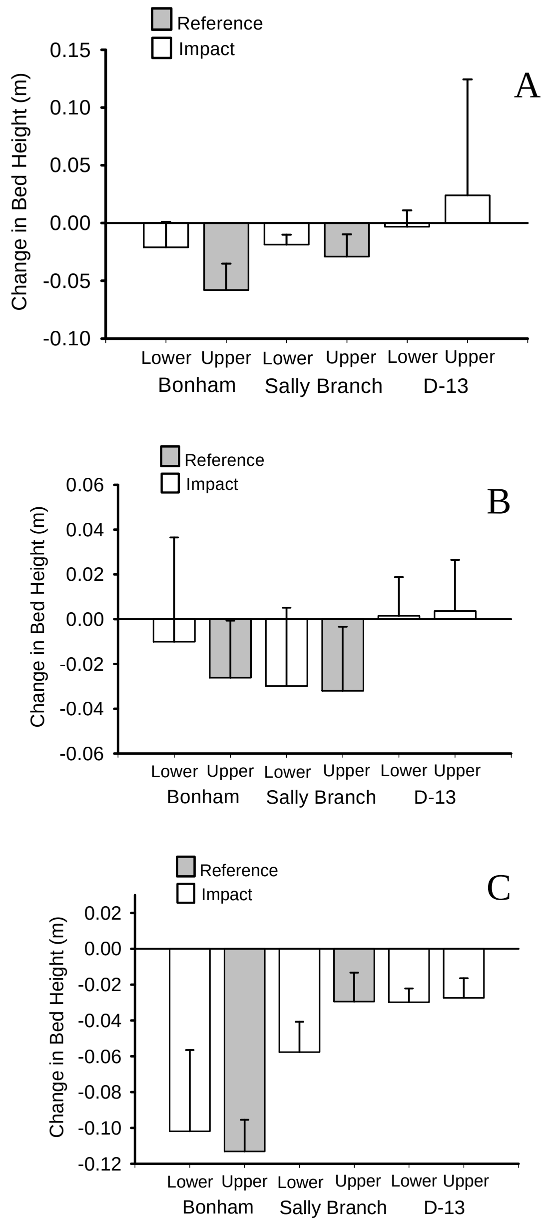


Figure 23. Mean (+1 SE) change in streambed height over the study, a measure of streambed (benthic habitat) stability. A.—Differences from Oct 2005 and May 2006. B.—Differences from Oct 2005 and May 2007. C.—Differences from Oct 2005 and May 2008. Both sites in D13 were considered impact sites because of the construction of a new stream-road crossing upstream of both sites in spring 2005.

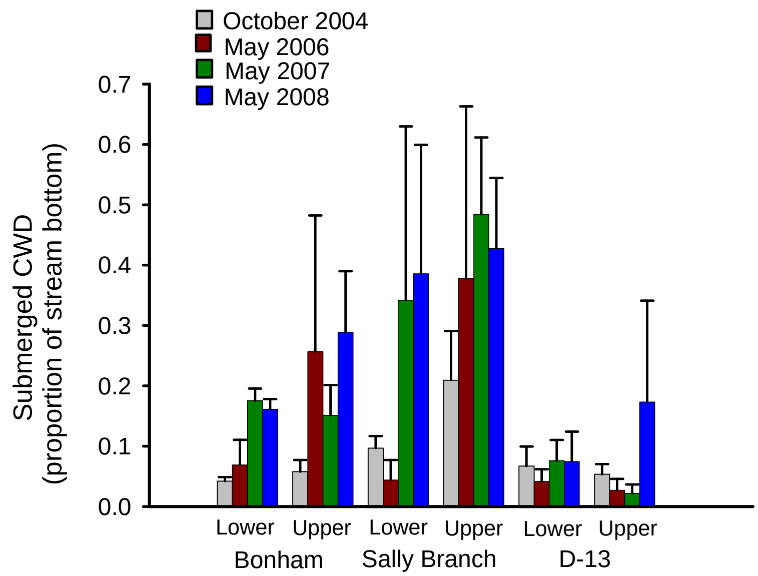


Figure 24. Mean (+1 SE) relative abundance of instream coarse woody debris (CWD), as indicated by the proportion of submerged CWD occurring in the stream bed, during the study (October 2004 – May 2008).

Benthic Particulate Organic Matter

The percentage of benthic particulate organic matter (% BPOM), a measure of instream benthic habitat quality, ranged from <1 to >4% of sample, and varied between lower and upper sites to different degrees depending on catchment and season (Fig. 25). Over the entire study % BPOM in Upper Sally Branch was $\geq$2% whereas values in Lower Sally usually were <1%, with the latter showing no decline over time ($p > 0.05$). % BPOM in Lower Bonham also did not change over the study, nor did Upper or Lower D-13 ($p > 0.05$, Fig. 25). As a result, there was no apparent DMPRC impact in terms of altered %BPOM in Lower Sally Branch, Lower Bonham, or Upper and Lower D-13 pre- vs. post construction.

For D13, the degree of difference in % BPOM between upper and lower sites in spring declined from 2005 (83% difference between upper and lower sites), to 2006 (58% difference), to 2007 (40%), to 2008 (7%). Decreased between-site differences from May 2005 (early DMPRC road construction) to May 2008 (post-DMPRC construction) may have, in part, reflected decreasing % BPOM in the upper D-13 site resulting from increased accumulation of inorganic matter during sediment accretion of the stream bed (Fig. 23).

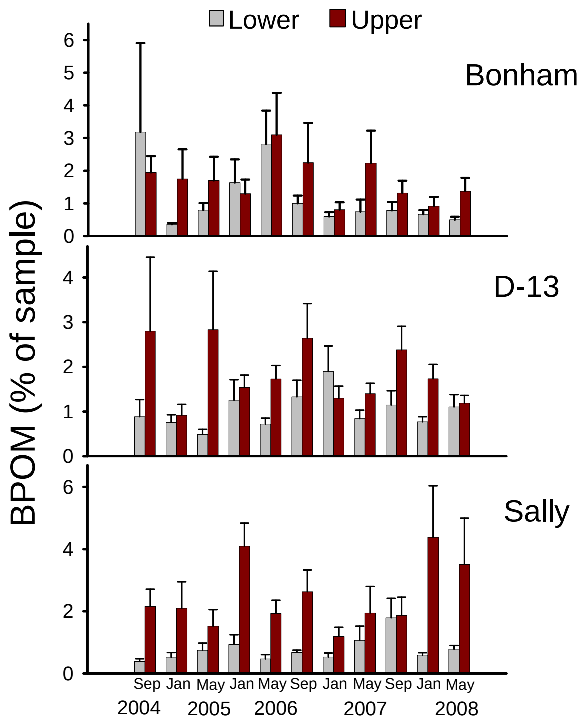


Figure 25. Mean (+1SE) abundance of benthic particulate organic matter (BPOM), as the indicated by the % of the streambed substrate as organic matter (determined by measuring ash-free dry mass, AFDM) in Bonham Creek (top panel), D13 (middle panel), and Sally Branch (lower panel) during the study (Oct 2004 – May 2008).

Algal Biomass and Diatom Composition

Benthic algal biomass (as chlorophyll *a* concentration), a measure of potential nutrient loading and community alteration in disturbed streams, varied seasonally in the study sites. Spring (May) and summer (September) samples showed generally higher chl-*a* than winter (January) samples (Fig. 26). There was no apparent DMPRC impact in Bonham Creek as lower and upper sites showed similar algal biomass over most dates. For Sally Branch, algal biomass spiked in the lower site in May and Sept 2007 and was significantly higher than the upper site ($p < 0.02$), but in 2008 between-site differences in biomass were indistinguishable ($p > 0.05$). Algal biomass also spiked in D-13 in May and Sept 2007, especially Upper D-13, and were significantly higher than corresponding seasonal biomass levels pre-DMPRC construction (upper and lower sites combined; $p < 0.0001$).

Algal biomass in Upper and Lower D13 decreased dramatically in 2008, and in May fell significantly below levels in May 2005, pre-DMPRC construction (upper and lower sites combined; $p < 0.0001$, Fig. 26). Increased chl-*a* in spring samples in D-13 corresponded with elevated DIN concentrations following DMPRC construction (Fig. 17). Algal biomass levels in spring 2008 were intermediate between 2007 and 2005, and also tracked declines in DIN during this time (cf. Figs 17 and 26). These results suggest

that higher algal biomass may have resulted, at least in part, from increased streamwater nutrients concentration post-construction, which decreased over the remaining sampling dates. Similar to D-13, Lower Sally Branch showed elevated algal biomass in spring and summer 2007 (Fig. 26), although within-site variation in chl-*a* concentration was higher in this stream than in D-13 (e.g., compare May 2005, 2006, and 2007chl-*a* levels in Upper Sally, Fig. 26), which precluded characterization of any measureable impact from the DMPRC construction.

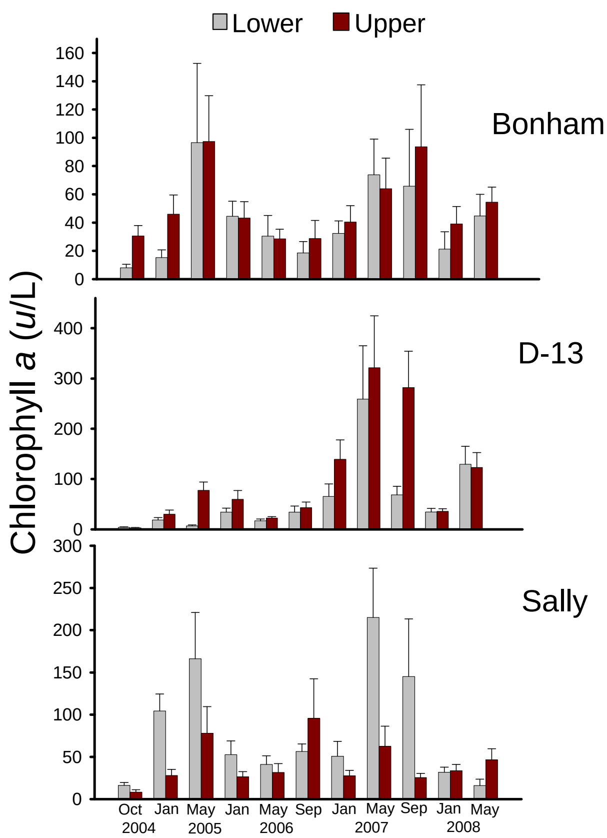


Figure 26. Mean (+1SE) concentration of benthic chlorophyll *a* (chl-*a*), a measure of in-stream algal biomass, in Bonham Creek (top panel), D-13 (middle panel), and Sally Branch (lower panel) from Oct 2004 – May 2008.

Diatom composition data (as % of the community composed of the sediment-intolerant diatom in the genus *Eunotia*) also were used to assess the degree to which diatom assemblages changed in relation to DMPRC construction. In previous work, this measure was useful in separating streams in disturbed and undisturbed catchments, as % *Eunotia* decreased with increasing disturbance (SERDP riparian project, CS1186; Miller 2006). In the present study, we analyzed seasonal samples from 2007 and 2008 to assess whether lower and upper sites in Bonham and Sally Branch differed from each other post-DMPRC, and whether assemblages in D-13 differed from early vs. late phases of DMPC construction in a manner similar to other biotic measures. Using this measure, % *Eunotia* did not differ between lower and upper sites for either Bonham or Sally Branch

($p > 0.34$; Fig. 27). Moreover, temporal comparisons in D-13 between 2006 (i.e., during early DMRPC construction) vs. 2007 (i.e., when other stream indicators showed potential impairment, above and following) indicated no similar response in both sites that was consistent with impairment. Year-to-year comparisons either showed no difference in % *Eunotia* (May; $p > 0.05$) or an unpredicted increase in this metric in Sept 2007 and early 2008 (Jan; $p < 0.05$). Thus, whereas % *Eunotia* is a useful indicator of disturbance among-catchments at Ft. Benning (Miller 2006) it may not be as effective in indicating potential changes attributable to DMPRC impact within individual catchments such as those in the DMPRC study.

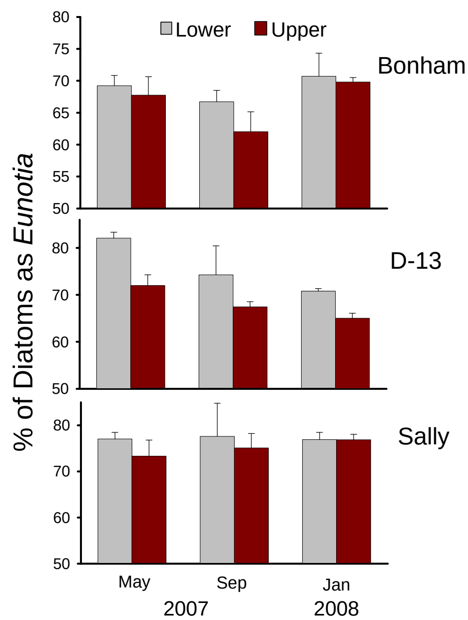


Figure 27. Mean (+1SE) percentage of the total benthic diatoms within the disturbance-intolerant genus *Eunotia*, as assemblage-based measure of change in stream diatom assemblages, in Bonham Creek (top panel), D-13 (middle panel), and Sally Branch (lower panel) from May 2007 – Jan 2008.

Benthic Macroinvertebrates

The following results for the benthic macroinvertebrates are divided into 2 main sections, 1) analyses of between-site (Upper vs. Lower) differences for the Bonham Creek and Sally Branch catchments, and 2) analyses of temporal variation in Upper and Lower D-13, the Bonham Creek tributary, before vs. after the DMRPC construction.

Results for Bonham Creek and Sally Branch.—Total benthic macroinvertebrate richness was low to moderate (20–55 taxa/date), which varied by stream, site, and season (Fig. 28). Over all dates, Richness at Bonham Creek was highest in the upper site in September 2006 (58 taxa) and lowest at the lower site in January 2008 (22 taxa); in contrast, richness at Sally Branch was highest in the lower site in September 2005 (57 taxa) and lowest at

the upper site in May 2008 (30 taxa). Between-site comparisons showed that richness at Bonham Creek usually was higher at the upper sites than the lower sites, and in 2006 this differential increased until 2008 (Fig. 28). In contrast, richness in lower Sally Branch was consistently higher than the upper site from May 2007 to September 2008, whereas prior to May 2007 peak richness varied from site to site. Using this metric, there appeared to be some short-term biotic impact of DMPRC construction at Bonham Creek (2006-2007) but not at Lower Sally Branch over the 4-y study.

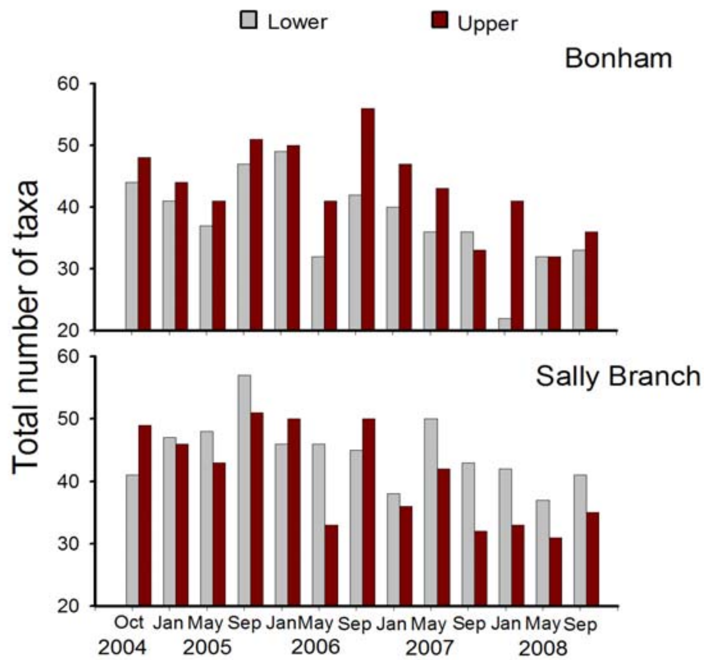


Figure 28. Total number of benthic macroinvertebrate taxa for Bonham Creek (upper panel) and Sally Branch (lower panel) for pre-DMPRC (2004), early (2005) and post-construction (2006 – 2008) periods.

Overall, Shannon's *H*' for Bonham Creek and Sally Branch showed no consistent difference between upper and lower sites over the study (Fig. 29), suggesting no impact from the DMPRC construction using this metric. Both streams experienced an overall decrease in diversity during winter (Jan) and spring (May) 2005. This decline may have resulted, at least in part, from high precipitation and stream discharge during 2005, which was one of the wettest years on record (unpublished data).

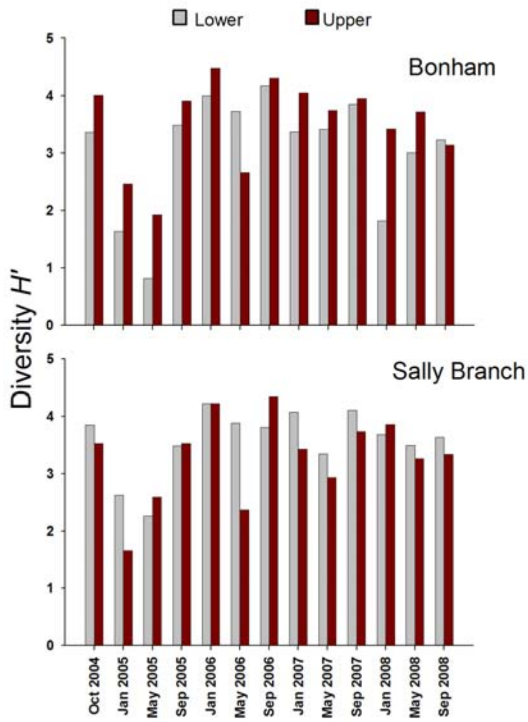


Figure 29. Shannon diversity (*H'*) of benthic macroinvertebrates in Bonham Creek (upper panel) and Sally Branch (lower panel) for pre-DMPRC (2004), and DMPRC early- and post-construction (2005 – 2008) periods.

The percentage of the total benthic macroinvertebrates occurring in the pollution-sensitive aquatic insect orders Ephemeroptera, Plecoptera, and Trichoptera (% EPT) generally was low (~20% or less) in both streams (Fig. 30). Seasonally, % EPT usually was highest in spring (May), lowest in winter (January), and intermediate in summer (September). For Bonham Creek, %EPT was higher in upper (vs. lower) sites, particularly in May 2006 and 2007 and Sept 2007 (Fig. 30). % EPT peaked in May 2006 in both Upper and Lower Bonham (35-55%), largely because of high abundances of the stonefly *Leuctra* spp. For Sally Branch, the upper site consistently showed higher %EPT than the lower site over the study, especially in spring and summer collections (Fig. 30). Peaks in % EPT for these dates mostly were the result of high abundances of *Leuctra* sp. stonefly nymphs, and also the hydropsychid caddisfly *Diplectrona modesta* larvae in spring 2007 samples. Using this metric, there appeared to be some short-term biotic impact of DMPRC construction in Bonham Creek in 2006 and 2007, but not in Sally Branch.

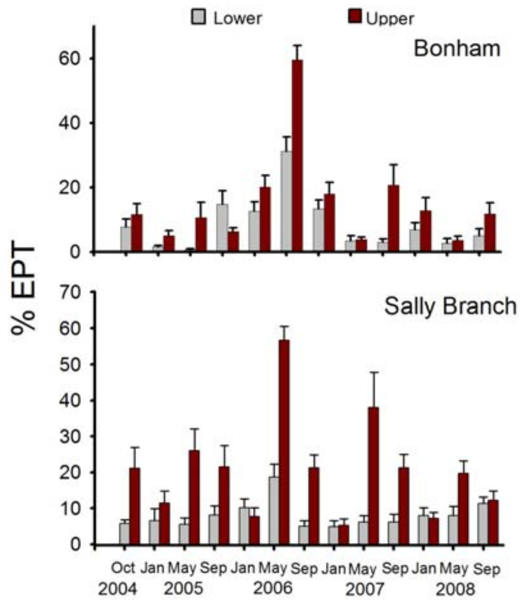


Figure 30. Mean (+1SE) % of the sensitive aquatic insect orders Ephemeroptera, Plecoptera, and Trichoptera (%EPT) for Bonham Creek (upper panel) and Sally Branch (lower panel) for pre-DMPRC (2004), and early and post construction (2005 – 2008) periods.

Total macroinvertebrate biomass at Bonham Creek and Sally Branch was variable over seasonal and annual sampling periods, with biomass ranging from ~20 to 300 mg dry mass /m^2 (Fig. 31). For both streams, there were no clear seasonal patterns in biomass over the study, or a consistent difference in biomass between upper and lower sites post-DMPRC construction. The only notable between-site difference occurred for Sally Branch from September 2006 through January 2007, where biomass at the lower site was ~50% of that recorded at the upper site (Fig. 31). It is conceivable that this difference reflected sedimentation inputs from the DMPRC construction. However, as shown by other macroinvertebrate metrics, these impacts were short term.

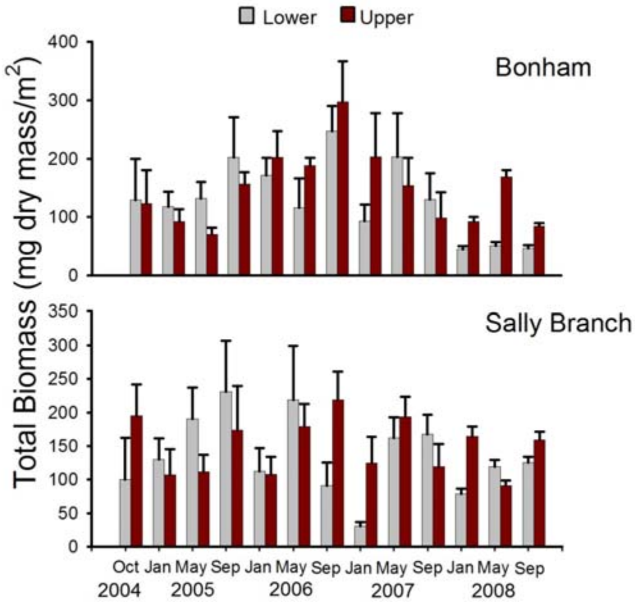


Figure 31. Mean (+1 SE) total benthic macroinvertebrates biomass in Bonham Creek (upper panel) and Sally Branch (lower panel) for pre-DMPRC (2004), and early and post construction (2005 – 2008) periods.

Examination of multimetric GAMMI scores from Bonham Creek and Sally Branch revealed that macroinvertebrate assemblages showed high seasonal and annual variation at upper and lower sites (Fig. 32). Both streams and sites showed a marked decrease in GAMMI scores in September 2006, which continued through January 2007. Lower scores continued through May 2007 for lower Sally Branch site, whereas scores in May 2007 for the upper Sally site and both Bonham sites returned to levels recorded from previous years. Overall decreases in Sept 2006 may have resulted from natural disturbance from high precipitation and stream discharge before this period (above), although this mechanism would not explain relatively high GAMMI scores in May 2006, which also occurred after the 2005 wet year.

Analysis of GAMMI scores revealed a difference between lower and upper Bonham Creek sites in October 2004 pre-DMRPC construction (t = 2.43, p = 0.035; Fig. 32), with lower sites showing higher scores than upper sites (mean = 46.46 vs. 38.01, respectively). However, factorial analysis of GAMMI scores over the study indicated no overall differences between upper and lower sites (F = 0.03, p = 0.861). Thus, an additional 4 ×2 factorial analysis was done to test between upper and lower sites during early and post-construction across 2005, 2006, 2007, 2008, and for the site-year interaction for summer samples. This analysis revealed no significant differences between upper and lower sites (F = 3.01, p = 0.092), although the lower site maintained higher scores than the upper site (mean = 49.48 vs. 44.36, respectively; Fig. 32). Use of the GAMMI metric indicated no significant impact of DMPRC construction on biotic integrity in Bonham Creek.

Analysis of Sally Branch patterns during pre-DMPRC construction (October 2004) revealed no difference in GAMMI scores between upper and lower sites (t = -1.06, p = 0.312; Fig. 32). Repeated-measures ANOVA showed no difference between upper and lower sites (F = 0.68, p = 0.430) nor a significant site-date interaction (F = 1.37, p = 0.199). However, inspection of the data showed a trend for upper sites to have higher scores than lower sites for many spring and summer samples during the post-DMRPC construction (Fig. 32). Thus, our inability to detect significant between-site differences for Sally Branch during this period may have reflected type I error attributable to high within-site variation using this metric.

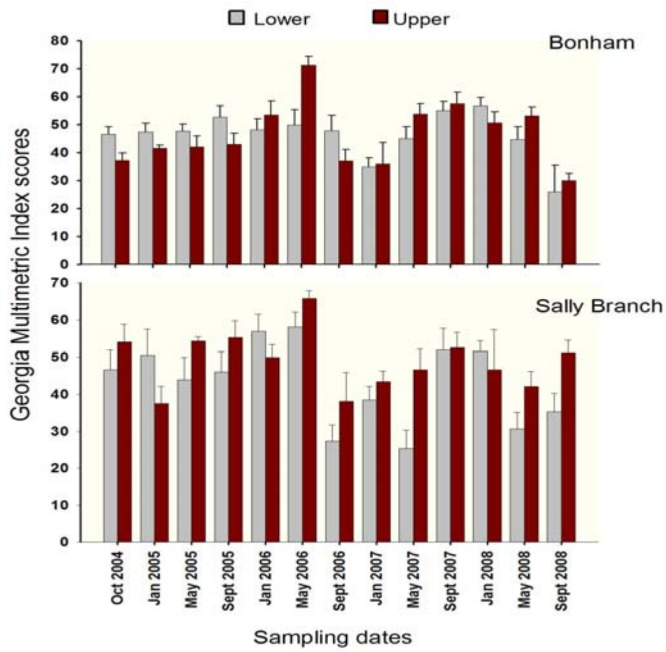


Figure 32. Mean (+1 SE) Georgia Multimetric Index scores for Bonham Creek (upper panel) and Sally Branch (lower panel) for the pre-DMPRC (2004), and early and post-construction (2005 – 2008) period.

Nonmetric multidimensional scaling (NMDS) ordinations for Bonham Creek and Sally Branch showed no clear classifications of Upper and Lower sites reaches for all seasons and years combined (Fig. 33). If construction from the DMPRC had a strong effect on assemblage structure (i.e., by reducing faunal similarity between lower and upper sites in a given post-construction year, or by reducing between-year similarity of assemblages within an affected site pre-vs. post-construction), then we would have expected shifts in assemblages reflecting increased dissimilarity pre- vs. post-construction. Instead, similar sites in the same sampling year either were spread widely in ordination space (e.g., BL2007; Fig. 33A), reflecting high seasonal variation, or were clustered with other sites sampled in the same year (e.g., SL2007 and SU2007 in top of Fig. 33B) or with those from disparate years within the DMPRC construction time frame (e.g., SL 2004 and SU2006 in upper right of Fig. 33B).

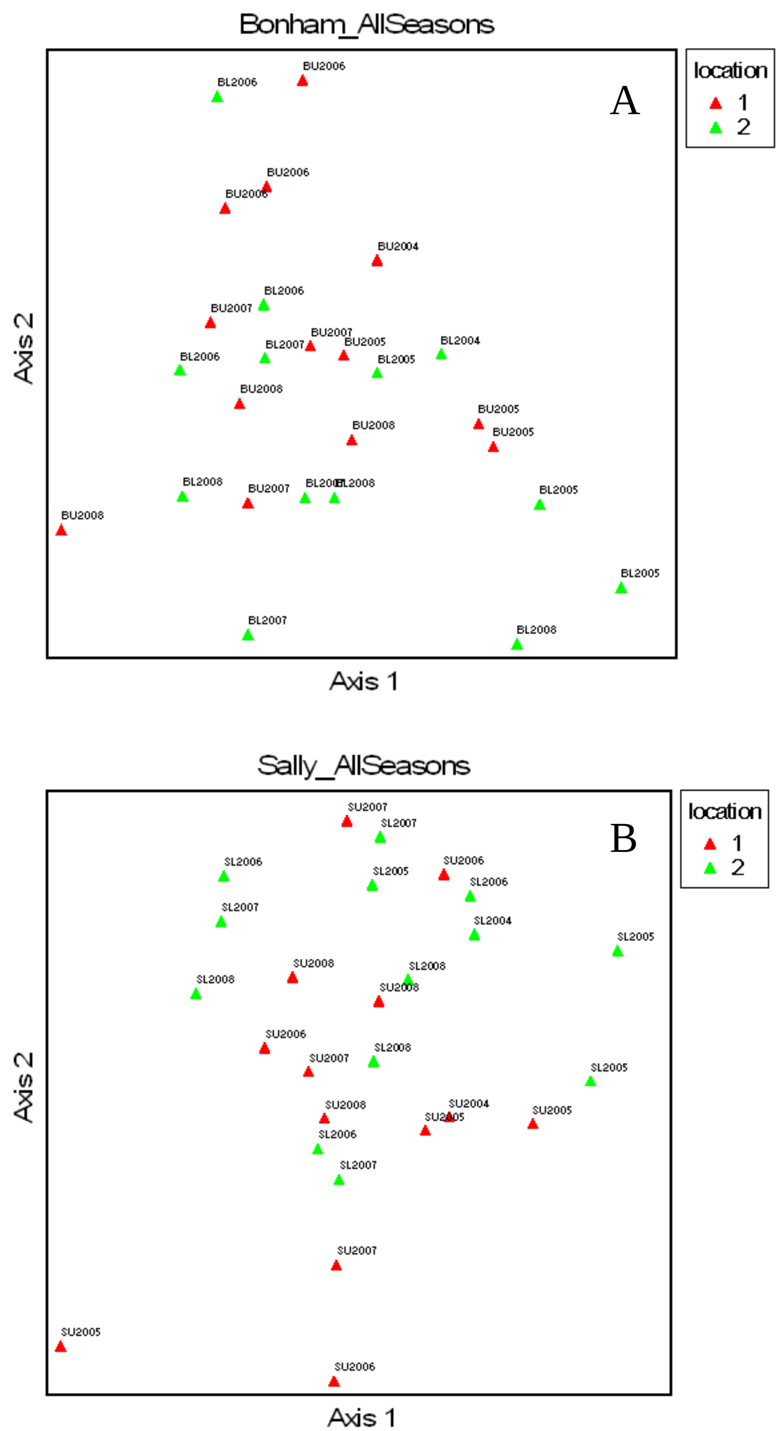


Figure 33. Nonmetric multidimensional scaling ordination of benthic macroinvertebrate assemblages for all years (2004-2008) and seasons, for Bonham Creek (A) and Sally Branch (B) catchments. Red symbols depict upper sites and green symbols depict lower sites for each catchment. Stress levels = 14 and 21 for A and B, respectively. BL=Bonham Lower site, BU= Bonham Upper site, SL=Sally Branch Lower site, and SU=Sally Upper site.

Results for D-13. —Analysis of GAMMI scores from summer 2000-2008 samples using GLM revealed a highly significant difference between pre- and post-DMPRC construction ($F = 17.35$, $p < 0.0001$). GAMMI scores of pre-preconstruction years were significantly higher than post-construction years (mean = 54.01 vs. 42.60, respectively; Fig. 34).

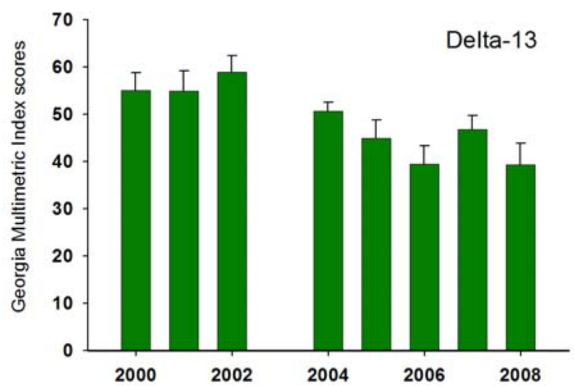


Figure 34. Mean (+1 SE) Georgia Multimetric Index (GAMMI) scores for D-13 summer samples, before (2000–2004), during (2005), and after DMPRC construction (2006 – 2008). No data were collected in summer 2003.

Inspection of the list of macroinvertebrate taxa present indicated that the high GAMMI scores during pre-DMPRC construction were mostly from changes in abundance of larvae in the caddisfly family Hydropsychidae. Many hydropsychid genera are considered sediment-tolerant, and larvae generally were rare in benthic samples throughout the pre-construction period except for *Diplectrona modesta*, a species considered sensitive to sediment disturbance. This species was largely replaced by the more tolerant genus *Cheumatopsyche* sp. in the period after DMPRC construction, which accounted for significant increases in Hydropsychidae and corresponding declines in % Hydropsychidae/% EPT metric scores during this period (Fig. 35).

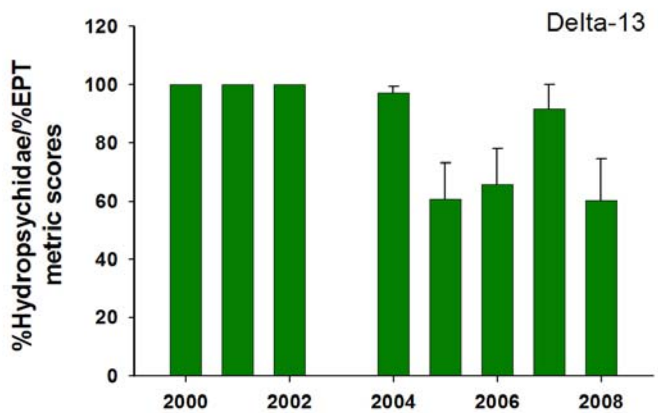


Figure 35. Mean (+1 SE) metric scores for the Georgia Multimetric Index (GAMMI) metric % Hydropsychidae/% Ephemeroptera, Plecoptera, and Trichoptera (EPT). Values are for summer samples. No data were collected in summer 2003.

Closer inspection of the hydropsychid taxa within D-13 indicated that the relative abundance of the sensitive taxa *Diplectrona modesta* + *Hydropsyche* sp. both were highest in winter and spring samples, declined after DMPRC construction began in 2005, and were entirely absent from samples taken from September 2005 to September 2007 (Fig. 36). During this period, *Cheumatopsyche* sp. increased substantially was the only hydropsychid group collected. Interestingly, *Cheumatopsyche* sp. was absent from 2008 samples, and was replaced by *Diplectrona modesta* and *Hydropsyche* sp. Based on changes in the presence and absence of these differentially tolerant species, it is likely that sediment disturbance from DMPRC construction activities accounted for some of the species turnover, with sediment-intolerant taxa replacing tolerant groups during and 2-y after construction, and intolerant groups re-establishing in disturbed sites once sediment impacts lessened and the sites showed some recovery in 2008.

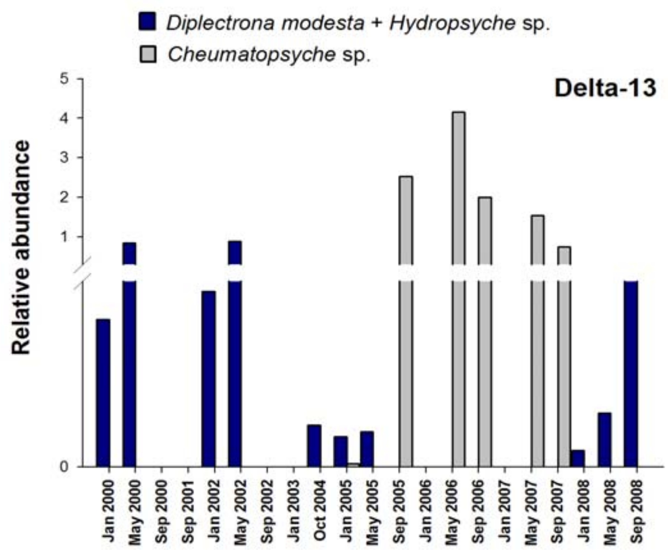


Figure 36. Relative abundance of the composite caddisfly family Hydropsychidae at D-13. January 2000–October 2004 was the pre-DMPRC construction period whereas January 2005 – September 2008 was the post-DMPRC construction period.

Changes in abundance of the sensitive stonefly *Leuctra* sp. also indicated shifts in instream conditions coincident with DMPRC construction (Fig. 37). *Leuctra* nymphs were most abundant in spring and summer samples collected prior to DMPRC construction; nymphs disappeared entirely from samples from May 2005 through September 2007, but were then recorded from both D-13 sites at abundances similar to pre-DMPRC construction levels in 2008. Taken together, strong shifts in hydropsychid species abundances and the presence and absence of *Leuctra* we observed indicated significant impacts in D-13 from DMPRC construction from 2005-2007, but a marked biotic recovery in 2008.

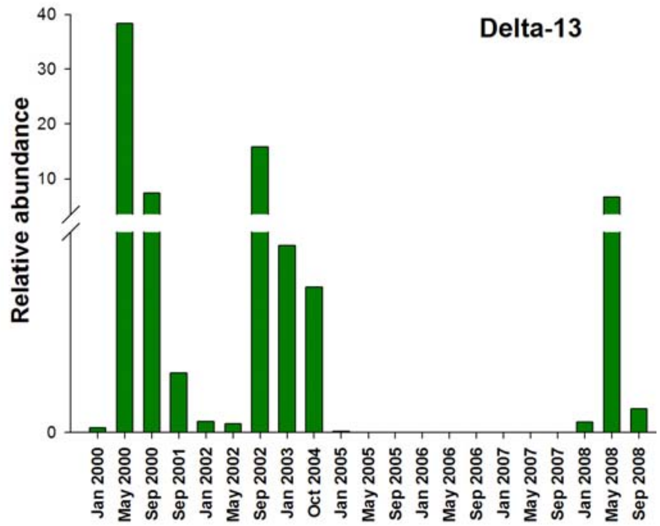


Figure 37. Relative abundance of the composite stonefly genus *Leuctra* sp. at D-13. January 2000–October 2004 was the pre-DMPRC construction period whereas January 2005 – September 2008 was the post-DMPRC construction period.

Stream Fish Assemblages (D-13).— We were unable to quantify fish effectively in Sally Branch or Bonham Creek sites because of the difficulty in electroshocking fish in these two large, low-conductivity streams. Moreover, the woody nature of these sites also precluded effective use of seines to sample fish assemblages. Electroshocking was effective in D-13 over the 4-year study, where we quantified fish richness and abundance annually. The number of fish collected declined dramatically from 2004 (pre-DMPRC construction) to 2008 (post-construction) in both upper and lower sites (Fig. 38). Fish richness also declined during the study, but only at the upper site where pre-construction levels were higher than that at the lower site (5 vs. 2 species, respectively). Unlike that observed for benthic macroinvertebrates, there was no clear indication of fish population recovery in D-13 in 2008 from the DMPRC construction, at least in terms of fish abundance.

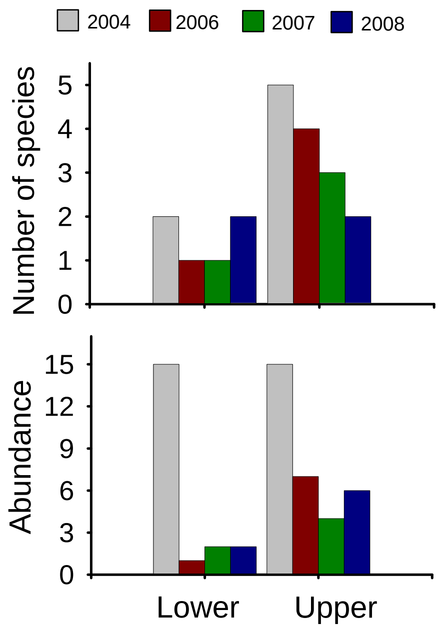


Figure 38. Comparison of fish richness species captured (number of species, top panel) and number of fish captured (abundance, bottom panel) for lower and upper sites in D-13 between Oct 2004 (before DMPRC construction) and June 2006, 2007 and 2008 (after DMPRC construction).

ACTION ITEM FROM 2008 IPR REVIEW:
In the addendum to your SERDP Final Report separate out the invertebrate taxa results to reflect differences between sediment tolerant species and sediment intolerant species for both control streams and impacted streams.

Use of the Georgia Multimetric Index (GAMMI, GA Environmental Protection Division 2007), which was estimated for each stream site over the 4-year study, includes information on relative abundance of sediment-tolerant vs. intolerant taxa. Thus, information on the average disturbance tolerance of invertebrate taxa is incorporated in this metric for a given date and site. In addition, in the tributary of Bonham Creek (D-13) where we had sufficient pre-DMPRC data we reported changes in abundance of several individual sediment-tolerant and sediment-intolerant macroinvertebrate taxa from pre- to post-DMPRC construction (above), including several taxa of hydropsychid caddisflies and a genus of stonefly. Collectively, data from GAMMI and focal taxa in D-13 suggested a dramatic impact of construction on the macroinvertebrate assemblage in 2006 and 2007, and a recovery of at least some disturbance-intolerant taxa in 2008. GAMMI data from 2008 suggested that some of the taxa had still not recovered in D-13 by the end of our study.

RECOMMENDATIONS FOR FUTURE WORK

We believe that our approach and set of measurements for determining impacts to Bonham Creek and Sally Branch resulting from DMPRC construction and eventual operation have met the project goals. Results presented here indicate that water quality in Bonham Creek and one of its tributaries (D-13) has been significantly impaired by sediments and, to a lesser extent, by increased inorganic nitrogen concentrations. Results from the Riparian Soils and Vegetation work indicate that forested areas adjacent to the DMPRC are stable and that little sediment movement seems to be occurring there. However, in spite of the severe 2007 drought, it is clear that soil export near road crossings at both Bonham Creek and Sally Branch is occurring. This situation should be expected to increase markedly once increased rainfall returns. We recommend continued monitoring of those areas and increased monitoring of areas around intermittent streams that flow into Bonham and Sally. We are unaware of the amount of time necessary for stream bank stabilization and additional data (covering periods with normal or higher rainfall) would be very helpful in determining stabilization trajectories.

Results of our water quality studies indicate that physicochemical water quality in Bonham Creek and its D-13 tributary was significantly impaired by large sediment inputs and, to a lesser extent, by increased inorganic nitrogen concentrations beginning in late 2005 and early 2006. There was evidence that these impacts on water quality were abating by 2008. However, beginning in 2007 there was evidence that sediment inputs to Sally Branch increased markedly as shown by high storm suspended sediment concentrations. In addition, storm inorganic nitrogen concentrations increased sharply in Sally Branch in 2007. It was not clear if storm suspended sediments and inorganic nitrogen concentrations were declining in 2008 in Sally Branch. We recommend that storm suspended sediment concentrations and inorganic nitrogen concentrations continue to be monitored in these streams to determine if DMPRC construction impacts are truly abating as suggested by some of our 2008 data.

Results of analyses on impacts of DMPRC construction on stream biota indicate virtually no impact at Sally Branch, minimal and short-term (1-2y) impacts in Bonham Creek, and significant impacts in D-13, the tributary of Bonham Creek. D-13 experienced alterations in a full suite of biotic and abiotic conditions including temporal shifts in streambed stability, increases in algal biomass, and alterations in benthic macroinvertebrate and fish assemblage richness, abundance and/or composition. Most of these impacts manifested for only 1 to 3 years, but by 2008 (4 years post construction) largely were undetectable as many measures returned to levels at pre- or early in DMPRC construction. It is likely that most biotic impacts in D-13 occurred from increased sedimentation in the channel attributable to upstream road construction, which, when stabilized, allowed recovery. We feel it is essential that sediment entry and transport into and through the channel be minimized for continued biotic community recovery in this stream, and we recommend that all stream communities potentially affected by DMPRC-related activities at Ft. Benning be monitored over as wide a range of hydrologic regimes (i.e., contrasting water years) and seasons as possible for as long as sedimentation is a potential environmental concern.

Finally, Bonham Creek and Sally Branch were moderately disturbed prior to DMPRC construction, so construction effects on these streams were likely not as great as would be observed for more undisturbed streams. This situation is particularly true for biological impacts, and is corroborated by the more severe impacts observed in the Bonham Creek tributary D13. Implementation of the DMPRC may offer an opportunity to improve biological conditions in Bonham Creek and Sally Branch if sediment delivery to these streams is reduced by more effective erosion controls. Therefore, we recommend continued monitoring of invertebrate biota and key water quality parameters (particularly suspended sediments and inorganic nitrogen) in these streams to identify possible recovery from past disturbances including historical agricultural as well as previous military training impacts.

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APPENDIX A

PROJECT PAPERS, THESES, AND PRESENTATIONS (cumulative for entire project)

Journal Papers:

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G. Cavalcanti, M.S. in Forestry, 2004, Auburn University. Thesis title: Effects of sediment deposition in above-ground net primary productivity, vegetation composition, structure, and fine root dynamics in riparian forests.

Kelly O. Maloney, Ph.D. in Biological Sciences, 2004, Auburn University. Dissertation title: "The influence of catchment-scale disturbance on low-order streams at Fort Benning, Georgia, USA". **(Received the 2005 Carolyn Taylor Carr Award from Sigma Xi Scientific Research Society for outstanding dissertation at Auburn University).**

Stephanie Miller, M.S. in Biological Sciences, 2006, Auburn University. Thesis title: "Relationships between wood and benthic algae: influence of landscape disturbance and decomposer competition".

Rachel Jolley, Ph.D. in Forestry, 2008, Auburn University. Dissertation title: "Effects of Sedimentation on Production, Nutrient Cycling and Community Composition in Riparian Forests Associated with Ephemeral Streams at Ft. Benning, GA, USA".

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